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FOURTH SERIES.

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WITH PLATE IV.

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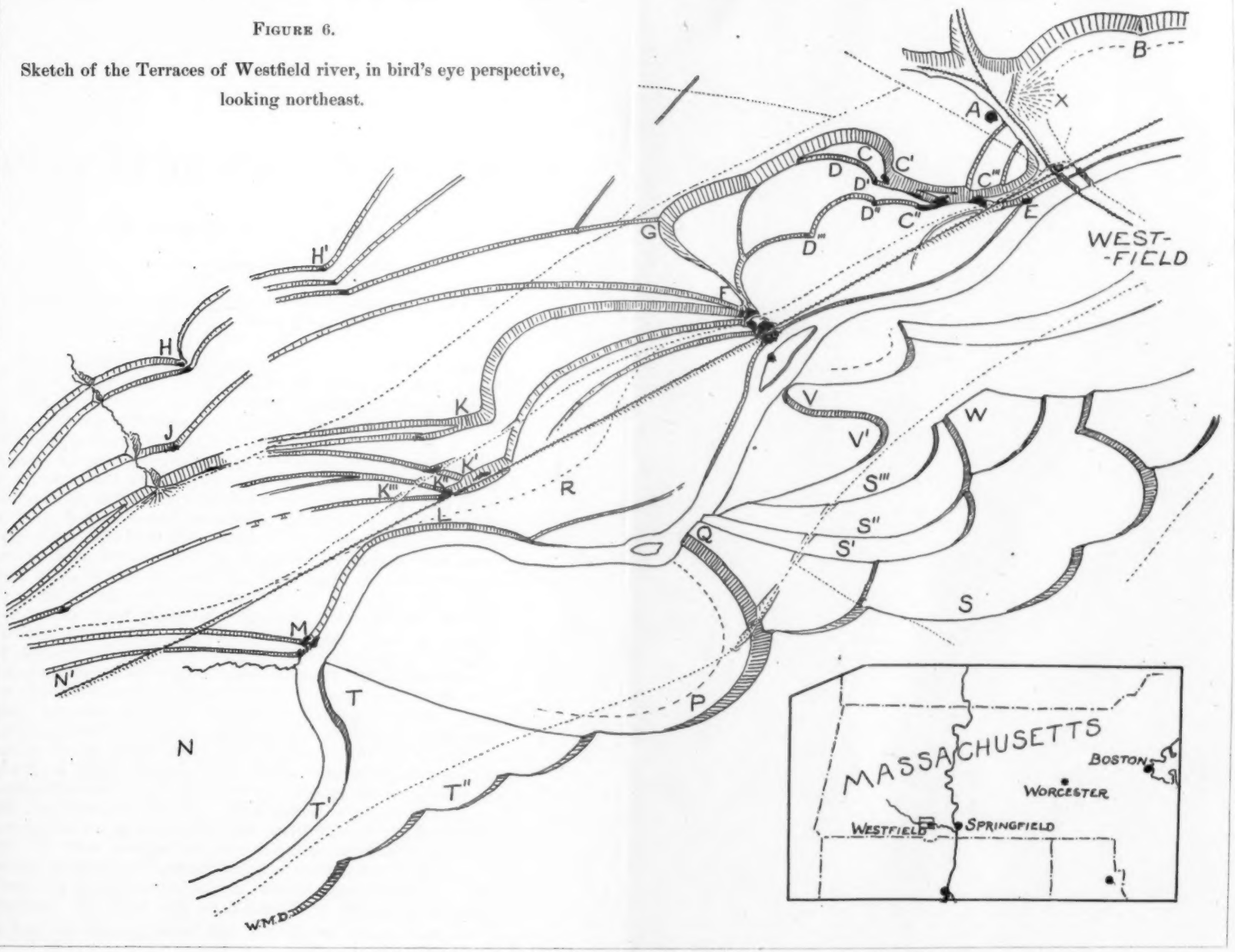
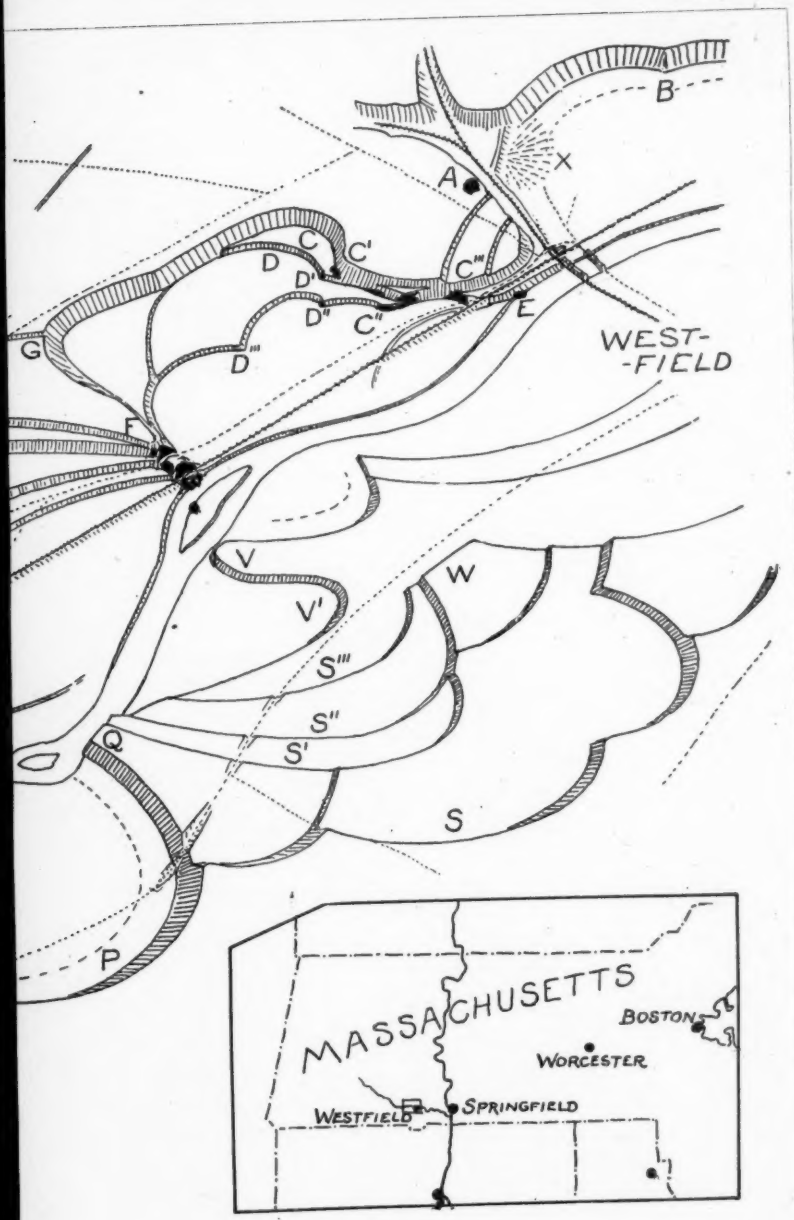
FIGURE 6.

Sketch of the Terraces of Westfield river, in bird's eye perspective, looking northeast.

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AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

ART. XIII.—*The Terraces of the Westfield River, Mass.;* by W. M. DAVIS. (With Plate IV.)

1. *The several theories of river terraces.*—The river terraces that are so abundantly developed in the stratified drift of our New England valleys, receive scanty explanation in the text-books to which reference is ordinarily made for accounts of such forms, and are, indeed, not exhaustively treated in essays of a more advanced character. Their most significant feature is an arrangement in the form of a flight of steps, of unequal tread and rise, and usually of unlike sequence on the two sides of a valley, but necessarily exhibiting a less cross-valley breadth between the terraces at the bottom of two opposite flights than between those at the top. It is generally agreed that each terrace plain is the remnant of a flood plain, that was formed during the process of valley-carving by the river that now flows on the flood plain or "interval" between the lowest terraces of the series; and that the terrace fronts or scarps have been carved by the wandering river as it swung laterally on its successive flood plains. The slope of the terrace plains down the valley and the pattern of the terrace scarps in curves concave towards the river, frequently uniting in cusps, give convincing proof of these conclusions. It follows that our terracing rivers habitually had a greater breadth of swinging on the flood plains at high levels, when beginning the work of sweeping the drift from their valleys, than at the low levels on which they are now flowing. The special point that needs to be accounted for is, therefore, the restriction of the belt over which the river swings to a less and less breadth in passing from the initial to the present stage of terrace development.

There are three theories which offer an explanation for this restriction. The first and most popular postulates a decrease

in river volume during and after the uplift of the region by which the erosion of the valley was prompted. The river is by this theory supposed to have been so large when terracing began that it needed a broad space on which to swing; now that the river has diminished in volume it is relatively enfeebled and is contented to swing over a narrower belt than formerly; so the later formed terraces do not undercut and destroy those of earlier date.

The second theory postulates successive uplifts of the region. The river, revived by each uplift, wears its channel beneath its previous flood plain and, on reaching grade, begins to swing laterally. It is then further postulated, sometimes tacitly, that the later uplifts have succeeded each other at shorter and shorter intervals, allowing less and less time for lateral swinging as the valley was worn deeper and deeper.

2. *Miller's theory of river terraces.*—The third theory, suggested in explanation of terraces in Scotland by Hugh Miller, the younger, in 1882,* recognizes slow regional uplift as the cause of valley erosion and then calls attention to the increase in the number of resistant obstacles—rock ledges, boulders, till—that the degrading river will encounter as it swings laterally while eroding the valley floor to lower and lower levels, and ascribes the decrease of interscarp breadth to this simple, effectual and observable cause.

As Miller's theory has not, to my knowledge, been quoted in this country, except in a brief note of my own,† a brief exposition of its merits may be made. I have found it very generally applicable to the terraced valleys of New England, and nowhere more so than in the valley of the Westfield river, between the eastern base of the Berkshire hills and the village of Westfield, Mass., a distance of about five miles, where I have repeatedly examined it. This district was the scene of an intercollegiate excursion in the autumn of 1901, in which Yale, Amherst, Williams, Wesleyan, Institute of Technology, and Harvard, together with six secondary schools, were represented by teachers and students to the number of forty-six; and it is not too much to say that at the end of the day's walk along the north side of the valley no doubt remained as to the competence of Miller's theory to explain the occurrence and the pattern of the terraces there seen. Decrease of volume and intermittent uplift seemed to be of altogether secondary importance, if indeed they had produced any recognizable effect.

The Westfield terraces.—The following pages give a brief account of the Westfield terraces, beginning with those on the

* River terracing, its methods and their results, Proc. Roy. Phys. Soc. Edinb., 1883, 263–305.

† Bull. Geol. Soc. Amer., xii, 1900, 483–484.

north side of the valley near Westfield railroad station, thence going west about two miles to a little settlement known as Pochassic Street; and returning by the south side of the valley to the village again. The general pattern of the terraces is indicated in figure 6 (Plate IV), where the attempt is made to show them in bird's-eye view, as if looking northeast from a height of two or three thousand feet above a point about a mile south of Pochassic Street. The scale in the further part of the view is somewhat smaller than in the foreground. The vertical scale is significantly exaggerated. The Boston and Albany railroad is not so straight as it is here drawn through the valley; about a mile and a half of its length is shown. Defending ledges are drawn in black. Roads are dotted.

3. *The open Westfield plain.*—Just north of Westfield station, a good view is had from the terrace near Prospect hill schoolhouse, A, figure 6, over a broad plain that the river has excavated east of the village. The plain is limited on the north by a single high terrace, B, rising at once from the marshy abandoned river channels at its base to the level of the highest drift plain of the district. On the opposite side the flood plain of the Westfield is confluent with that of (Westfield) Little river (not shown in fig. 6), limited on the south by a single high terrace, to-day undercut by Little river at two places. The low plain thus gains the unusual breadth of a mile or more for a distance of about two miles eastward from our point of view. The two rivers here show no incompetence whatever in the process of lateral swinging. Whatever loss of volume they may have suffered—and some loss since the disappearance of the ice sheet is highly probable—and however recent the last uplift of the region may have been, these two streams are here sweeping over a broader valley floor to-day than they have opened at any earlier time; for whatever earlier flood plains they have formed at intermediate levels, during the process of excavating their valleys, are now completely undercut and destroyed (except for a few low terraces) by the opening of the present broad plain. The prime reason for so striking an exhibition of competence on the part of the streams is believed to be the absence of rock ledges in this section of the valley. No ledges have here been discovered by the degrading streams; their high terrace scarps consist of clays, sands and gravels (the latter near the top), very easily eroded wherever the streams flow against their base, as may be seen where Little river is now swinging against the terrace scarp on the southern side of the plain. A secondary reason for the competence of the river to swing so broadly at the present level is probably to be found in the delay of further valley-deepening and in the resulting detention of the streams

close to their present grade by the trap sheet which their united current has come upon in the notch in the trap ridge about two miles east of Westfield.

4. *Terrace diagrams.*—The single high terrace scarp, here so well developed and typified in figure 1, is of more general occurrence in the terraced valleys of New England than is generally supposed to be the case. It may indeed be taken as typical of many terraced valleys where no ledges have been discovered to prevent the free swinging of the rivers. A few lower terraces may still be unconsumed here and there, as in figure 2; this arrangement of terraces also being of common occurrence where ledges are wanting. The ordinary diagram of a terraced valley, such as is here reproduced in figure 3, is therefore misleading in implying that the stepping terraces have been carved in drift alone, without relation to the rock beneath. These many-stepped flights of terraces need for their preservation a number of ledges, as in figure 4; but this figure is very faulty in implying that ledges occur all along the base of the terrace scarps. As a matter of fact, the ledges do not occupy more than a small percentage of the terrace lengths, and far from all lying on the line of a single cross section, as figure 4 implies, they are frequently distributed somewhat irregularly up and down the valley sides. The true relation of ledges and terraces is better shown in a block diagram, such as figure 5; and even here the area of the ledges exposed in the terrace cusps is exaggerated over that commonly observed.

5. *The Westfield spur (Prospect hill).*—If the terrace by Westfield station is now crossed to the west, it is soon found to be a spur of a high, but not of the highest plain, extending forward (southward on the north side of the valley) from the broad plain in the background. It is known as Prospect hill. The apex of the spur, E, figure 6, reaches the river; its breadth, east and west, is about a quarter of a mile. From its western side the valley floor again widens, making a recess or re-entrant in the high plain on the north; but here four subordinate terraces are found beneath a stronger scarp that rises to the highest level; they combine in a charming landscape, when seen from the western scarp of Prospect hill. As the river is thus found to have been competent to widen its valley both east and west of the terrace spur, some reason for the preservation of the spur should be looked for; and it is discovered clearly enough on descending the western scarp, which is found to be defended at various points along its bank by sandstone ledges, C′, C″, C‴. The sandstones are, to be sure, relatively friable; they are weak compared to the schists and gneisses of the Berkshire hills to the west; so weak, indeed, that while the Berkshires retain in the equable height of their uplands a

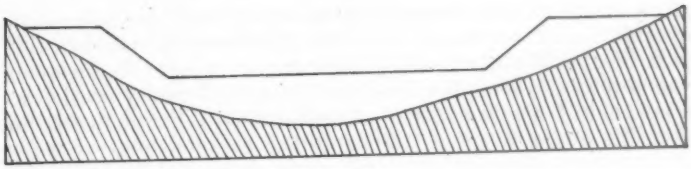


FIG. 1

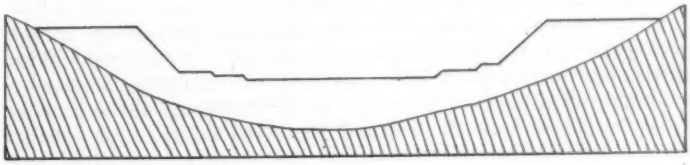


FIG. 2

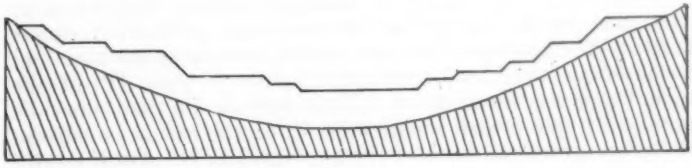


FIG. 3

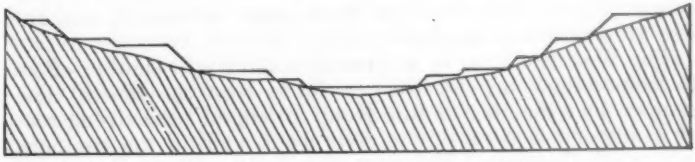


FIG. 4

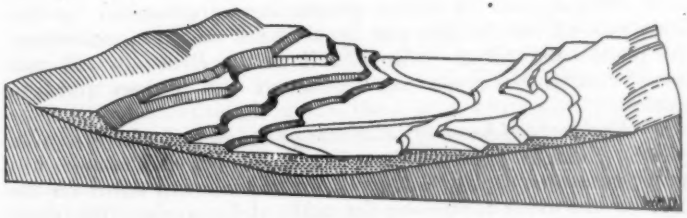


FIG. 5

fair indication of the altitude to which the Cretaceous peneplain of this region has been raised, the Triassic sandstones in this part of the Westfield valley (part of the greater Connecticut valley lowland) have been reduced by later Tertiary erosion to a lowland of a second (or $n+1$) generation. Yet compared to the silts and gravels of the terraces, the sandstones are very strong; whenever the river has, in the process of sweeping the drift from its valley, swung against a sandstone ledge, previously buried, further lateral swinging has been peremptorily stopped and the terrace behind the ledge has been preserved.

It is evidently because of the abundant defending ledges here that the Westfield spur has not been destroyed. The stream has made a most determined effort to destroy the spur by scouring out a hollow, C, at its back, sweeping around in so great a curve that its normal eastward course was locally turned back to the southwest; but the ledge, C′, on which the stream was caught, could not be removed, and hence the spur still stands there. The river seems to have been withdrawn from the deep recess, C, by taking a short-cut across a more axial part of the valley floor of that time, probably during a flood. When it again swung northward towards the recess, at a somewhat lower level than before, a lower part, D′, of the same ledge was encountered a little farther forward than the point, C′; and a small lunate area, C, of the earlier sweep was therefore preserved back of the new terrace, D. On the third return of the river into the same locality at a still lower level, it was caught by a small ledge, D″, several hundred feet farther forward, and again by larger ledges, C″, C‴, and hence a good stretch of the flood plain between D′ and D″ was preserved in a terrace.

The Westfield river is at present making still another effort to remove the spur, and it is now for at least the fourth time stopped by a member of this group of ledges, for a strong reef of sandstone is seen in the river bank at E in the southern corner of the spur. The spur may in the distant future be somewhat sharpened by losing ground on its undefended southeast corner, should the river chance to swing that way; but such swinging will be for the present strongly resisted by the buttresses of two bridges and by artificial embankment where the Boston and Albany railroad follows the river; it will cost less to restrain the river than to remove the bridges and the tracks.

6. *No local evidence of decrease of volume in the Westfield river.*—Evidently the preservation of the spur of Prospect hill is not due to any incompetence or to any want of effort on the part of the river to remove the sands and gravels. The river has repeatedly and energetically attacked the spur; it has in

the most competent fashion swept away all the drift that could be reached. It was only upon encountering the stubborn resistance of an ambushed and impregnable ledge that the river first withdrew, and even then it withdrew only to renew the attack by returning bravely toward the spur on a later swing. Unfortunately for the reputation of the river, the ambushed ledges have been found entrenched farther and farther forward at every successive attack that has been made upon them; hence the river, losing ground at every advance, has come to be looked upon as a weakened and shrinking stream that voluntarily abandons its earlier enterprises and accepts a narrower limit for its conquests to-day than when in a youth of (imagined) greater vigor and aggression; but this is a most unjust interpretation of its behavior. The river is making a most determined and heroic effort to carry out its original plan of campaign. It is eminently successful in opening the valley east of Westfield, and if it is defeated at the spur, this is only because of the reinforcement of the unconsolidated drift by the invincible strength of the entrenched ledges. The river may be accused of want of foresight in not more carefully reconnoitering the ground that it originally proposed to excavate, but it is notorious that rivers are heedless of buried ledges, on which they often become inextricably superposed. The river may be thought headstrong to return to an attack, a forlorn hope, where defeat is inevitable. Heedless and headstrong it may be, but it does not deserve the reproach of being looked upon as enfeebled. Even if its volume is now less than formerly, the river is as competent to-day as it ever was to open a wide flood plain in drift, and it does so wherever free opportunity is offered of carrying out its original enterprise.

7. *Relation of ledges, terraces and river swings.*—It should be noted that the ledges of the Westfield spur have not in any case determined the depth to which the river has cut its valley. The ledges here were not encountered in the river bed but in the river bank, and hence have controlled only the breadth of lateral swinging at the point where they were by chance discovered. The depth at which the ledges were encountered was dependent simply on the amount of valley excavation that had been accomplished by the graded river at the time that the discovery was made. It is also important to note that while a ledge thus encountered in the bank of a swinging river will defend and preserve that part of any flood plain previously formed at a higher level, above and back of the ledge, it is not at all necessary that every former flood plain of the river should be thus recorded. If the successive northward swings of an east-flowing river have by chance less and less ampli-

tude, successive terraces will remain, even without defense by ledges. There can be no question that some of our terraces are of this accidental kind. But the undefended lower terraces will be undercut and destroyed if the river swings more strongly north again. If the river again swings north until it strikes a ledge, the uppermost terrace may alone be preserved, and that only back of the defending ledge. It thus becomes evident that in order to discover the number of times that a river has swung across its valley, making laterally sloping flood plains at lower and lower altitudes at every swing, we must not trust to the chance preservation of flood plain remnants in terraces here and there, but must seek a flight of terraces, systematically grouped on a long sloping ledge, which may preserve a lateral remnant of every flood plain that has been formed, as in figure 5. It is certainly a striking fact that the number of steps in a flight of valley terraces always reaches a maximum in just such situations. The preservation of numerous terraces of moderate height on long sloping ledges—however few such ledges there may be in the valley and however few terraces occur elsewhere on the valley sides—goes far towards excluding the theory of successive uplifts and pauses as a cause of terracing. It goes far also towards supporting the theory that the wandering river has been swinging from side to side across its valley, always degrading its channel but always acting as a graded river, during the whole period of terracing, whatever may have been the cause that determined the excavation of the valley drift. If uplift were the cause, the uplift must have been slow and relatively uniform.

In illustration of this conclusion, we may return for a moment to the broad basin east of Westfield. No terraces at intermediate levels are found here to prove that the river did repeatedly swing laterally while degrading its valley floor in this part of its course; yet there can be no reasonable doubt that the river really did swing back and forth here, for the remnants of four flood plains at intermediate altitudes are found in the terraces on the west side of Prospect hill, only half a mile away. Farther up the valley one may find a flight of nine defended terraces, described below, whose subequal heights range from ten to fifteen feet; thus proving that even the four terraces on the Westfield spur preserve a very incomplete record of the river's activity. Evidently the maximum number of steps observed in any terrace flight gives only the minimum number of swings that the river may have made during the whole period of degradation.

8. *Ledges outcrop on the up-valley side of terrace spurs.*—In the terrace spur here called Prospect hill, as in many others, it is noteworthy that the up-valley side of the defending ledges

has been clean swept by a swinging curve of the attacking river. This may be explained as a result of the normal progress of a river meander down the valley, until it is stopped by coming on a ledge, or abandoned by withdrawal of the current to a short-cut or cut-off course. The fact of the down-valley progress of a meander does not seem to have received much attention from physiographers, judging by the silence of text-books concerning it; but it must be a familiar matter to river engineers, so conspicuously is it exhibited on such maps as those prepared by the Mississippi River Commission. The cause of the down-valley progress is evidently to be found in the continued displacement of the thread of fastest current to the down-valley side of the channel on entering the tangent of inflexion between two meander curves.

9. *Brown's spur.*—On the other hand, a terrace may trail some distance down-valley from its defending ledge, unless the stream should by any chance swing in again and sweep it away. This chance has not happened in Prospect hill, the spur thus far considered; but it has in Brown's spur, F, half a mile farther west. This spur is well defended by a large sandstone ledge, at whose forward-reaching base the river is now flowing in a vain effort to widen its valley. Four terraces in the next up-valley reëntrant curve forward to the apex of the spur, and all agree in the most unanimous manner to sweep tangent to the slope of the defending ledge. The ledge is well exposed in the cuts made by the passing road and railroad. The scarp of the next higher terrace, G, is, however, pushed back a quarter of a mile farther north; evidently because when it was made the river was swinging at a slightly higher level than the summit of the defending ledges in the apex of Brown's spur. It seems undeniable, when one looks at these terraces on the ground, that the river would have pushed back the lower members of the series about as far as the higher member, if its lateral swinging had not been stopped by the ledge.

The peculiar feature of this spur is, however, the close trimming that it has suffered on its down-valley side. The river has at least three times swung northward so near the eastern side of the ledge as to narrow the spur into a sharp point. The normal down-valley progress of the meanders cannot be appealed to as a cause of this close trimming on the down-valley side of the ledge; some special cause must be looked for to direct the several northward swings of the river over so nearly the same course. It seems probable that some constraint has been exerted on the river further up its channel, whereby it has been repeatedly guided to the down-valley side of the ledge. A possible explanation of this peculiar feature will be suggested on a later page.

10. *The flight of terraces by Pochassic Street.*—The finest flight of terraces hereabouts is preserved a little east of a small settlement, known as Pochassic Street, on the southeastern slope of Pochassic hill, a drumlin, around whose base abundant ledges have been discovered. The settlement and drumlin are just to the left of the limit of figure 6. The highest terrace, H, shows waterworn cobbles and pebbles on its plain; the bouldery slope of Pochassic hill rises behind it. Terraces are usually counted upward from the valley floor in the reverse order from that of their production. It will be convenient here to follow the natural order and count downward, beginning with the plain and scarp of the highest terrace as number one. Thickets of small trees and bushes obscure many details here, and some of the terrace plains are inconveniently swampy near their back border, perhaps because of ledges farther forward by which the ground water is held up. Hence the correlation of some of the terraces in this locality is doubtful, as indicated by the blanks left in the figure. A flight of at least nine steps, H–M, may, however, be counted, all presenting characteristic concave fronts in what may be called the Pochassic reëntrant, all curving forward at their down-valley ends to defending ledges, and all of similar height, roughly from eight to fifteen feet. A later terrace occasionally undercuts an earlier one, so that the two scarps are locally united in a slope of more than the average height; such being the case with the fifth–sixth scarp, along whose base lies a narrow country road in the middle of the reëntrant; a little farther east and west the scarp is divided into two (or more) parts by a narrow terrace that comes forward at an intermediate level; thus what seem to be the fifth and sixth swings of the river may be identified.

The uppermost terrace may be followed along its scarped front through the second growth of bushes and trees past two defended cusps, H and H′, beyond which it turns to the northeast and at a distance of half a mile or so seems to run tangent to another drumlin. The second terrace is not identified on the first ledge, H, but appears on the second, H′; it seems to fade away on the broad plain a quarter of a mile to the northeast. The third terrace is caught on both ledges, H and H′; it then runs eastward half a mile and is undercut at G by the large reëntrant between Prospect hill (the Westfield spur) and Brown's spur. Shortly before it is cut away, a low terrace turns off northeastward from it and seems to continue some distance; hence what has just been called the third scarp might be taken to represent the fourth northward swing of the river.

It is important to note that the sharp curvature and large arc of the reëntrants in the first and third scarps in connection with the ledges at H and H′ are much more consistent with the

behavior of a river similar in volume to that of the present Westfield than with the behavior of a much larger river.

The fourth terrace in the Pochassic reëntrant is caught on a ledge of loose-textured sandstone, J, that stands forward from the first small reëntrant in the higher terraces. The ledge is not directly exposed, but abundant angular fragments of pebbly sandstone are found in the apex of the blunt cusp on the terrace front. This terrace is believed to be the one that runs forward in a long sweeping curve to the apex of Brown's spur; but it has not been followed all through the bushes and some details of its form may not be shown in the figure.

The divergence between the eastward course of the third and fourth terraces, G and F, is highly significant. The third scarp was cut a quarter of a mile back of what is now the apex of Brown's spur, because at the time of the third northward swing of the river, its channel had not been worn deep enough to catch upon the summit of the ledges in the spur. But at the time of the fourth northward swing the river had eroded its plain to a lower level, so that it was held by the topmost ledge. The fourth terrace, therefore, could not be cut so far back as the third; it makes a long sweep forward from the Pochassic reëntrant to the apex of Brown's spur and leaves a rather broad plain between its scarp and that of the third terrace. It is perfectly evident that this arrangement of the two terraces was not due to any decreasing strength on the part of the river, but to the constraint imposed upon its wandering by the ledge at F.

11. *Perry's spur.*—Below the fourth terrace, J–F, come several others, which run forward to the rounded front of Perry's spur, K, K′, where several blunt cusps are determined by ledges of very friable sandstone that would hardly be seen but for cuts made by the road and the railroad. This item is of importance, for it shows that certain ledges which are strong enough to defend a terrace are not always bold enough to keep themselves in sight. After having done their duty in fending off the river, they strategically weather under cover and thus ambush themselves again beneath a thin sheet of their own waste mixed with creeping drift from the terrace they have protected. It is possible that another example of this kind may be found in the well defined cusp, D‴, of a low terrace in the reëntrant between Prospect hill and Brown's spur; it seems at first to be only the free intersection of two curves, for there is no sign of a ledge at its base and there are no angular fragments of sandstone by which the presence of an ambushed ledge is sometimes revealed. A little digging or a boring with a soil auger would suffice to determine this point.

The indefiniteness of some of the terraces in the Pochassic reëntrant may be due to the discovery there of till underlying

the stratified drift. Till is seldom well carved by a swinging river; its texture is significantly firmer than that of stratified sands and clays. A small stream coming out from the north cuts little trenches in the terrace fronts and spreads its gravel fans on their plains, thus further obscuring their forms.

The eighth and ninth members of the Pochassic flight are well defined, but instead of conforming to the concave pattern of the higher members of the series, they spring forward to a defended cusp, M, nearly opposite the middle of the reëntrant. Here as elsewhere it is perfectly evident that the failure of the river to cut back these lower terraces is not due in the least to any loss of its original strength, but to the increase of resistance offered by the ledges. The river has now swung away from the northward meander that it followed while carving the lowest terrace, N′, to a correspondingly strong southward meander, T′, which is now cutting a low terrace, T, on the south side of the valley. A broad flood plain, N, has thus been opened. It happens curiously enough that the down-valley progress of this southward meander has just now brought it to such a position that it is impinging against a large exposure of the sandstones at M. The normal down-valley advance of the meander, T′, will soon carry it past the ledge, unless the caving bank at T is protected. For the present, the obstruction caused by the ledge in the normal flow of the river seems to have produced a slight bend in the channel a little farther upstream. When the meander is sufficiently advanced the river will impinge directly on the unprotected bank between M and L, and consume it rapidly, leaving a sharp cusp at M. It is probably in some such way that the sharpening of Brown's spur, referred to above, has been accomplished. There has already been some undercutting of the low terrace east of M, for the main valley road was swept away by the northward swing of the river at L a few years ago. The road has been set back so as to cross Perry's spur, K′, north of the railroad, thus causing the desertion of several houses on the low plain, R, in front of the spur. The railroad itself is threatened by the river near L; the caving bank has been worn back dangerously near the track, and a quantity of coarse rock blocks has been thrown in there to stop the caving. But for this resistance the river would probably continue to swing northward until it encountered a low member of the group of ledges in the southwest base of Perry's spur, K′.

West of Pochassic Street another large reëntrant has been swept out on the north side of its valley; its down-valley side is well defended by ledges in the southwest base of Pochassic hill.

The flight of nine terraces in the Pochassic reëntrant, above described, constitutes the best series in the valley, as far as I have seen it. Closer study will probably increase the number of steps. The subequal height of the scarps suggests that these terraces record nearly every northward swing of the river in their locality. A similar number of swings has probably occurred elsewhere; the record of them is incomplete or wanting only because of the absence of defending ledges. It may therefore be concluded in general that it is only in localities well provided with ledges that one may expect to see preserved in terraces the lateral remnants of all the flood plains that were formed by the swinging river during the excavation of its valley; and that the maximum number of steps in a terrace flight is only the minimum number of lateral swings made by the river. All of these terraces testify to the graded condition of the degrading river at the time the terrace plains were made. The nine chance samples of river condition thus preserved may be fairly taken to show that the degrading river was meandering and swinging at grade during the whole period of terracing in this section of the valley. There is no indication that the individual terraces depend in any way whatever on individual uplifts.

12. *Terraces south of the river.*—The terraces on the south side of the valley may now be considered. No ledges are seen on this side of the river within the two-mile stretch included in figure 6. The first ledges are found half a mile further west; they defend the eastern or down-valley side of a strong reëntrant a little west of the town farm. Correlated with the prevailing absence of ledges is the absence of upper terraces. The high plain is habitually bordered by a strong scarp of forty or more feet, beneath which there may be several low terraces; but in one case the low flood plain of the present river enters a strong reëntrant, P, to the base of single scarp by which the whole descent is made from the high plain. Nowhere in this district is there a flight of low-scarped terraces from the top to the bottom level on the southern side of the valley. The reason for this contrast between the two sides of the valley may be with confidence ascribed to the general southward shifting of the belt within which the river swings, because of the southward slope of the ledges on the north side of the valley and the undefended condition of the terrace drift on the south side of the valley. It is a sort of monoclinal shifting of a river course. The several low terraces on the south might seem at first to contradict this explanation. They may, however, be reasonably explained as being not yet swept away. The river cannot attack the whole length of the southern side of the valley at once; it will swing against the southern

terraces only here and there, now and then; and hence the destruction of the lower southern terraces by the southward shifting of the belt of river-swinging can only be accomplished progressively. Thus viewed, it is no wonder that some of the lower southern terraces still remain. This corollary to the explanation above suggested receives much support when examination is made of the relation between the defended cusps of the terraces on the north and the concave reëntrants of the terraces on the south, to which we now proceed.

13. *Correlation of terraces on the two sides of the valley.*—It will be readily understood that, wherever a terrace scarp curves forward from a concave reëntrant to a defended cusp, the river must have once flowed along the base of the scarp and must have continued the line of the terrace curve past the cusp toward the opposite side of the valley, there to recurve toward the general valley axis. The farther forward the defended cusp reaches toward the axis of the valley, the more likely it is to direct the departing river strongly against the terraces on the opposite side of the valley. Thus the curved scarps, K′, K″, K‴, of the northern terraces, suggest that the river has formerly flowed on past the defending ledges of Perry's spur at these several levels and has thus entered the reversed curves of the southern scarps, S′, S″, S‴. The levels of the terraces concerned seem to correspond by pairs, but they have not yet been accurately measured. Of the three northern scarps, the one leading to K′ has the strongest curvature, for the middle of its reëntrant is cut farther back than the middle of the others. When the river flowed at the base of this scarp, its current must have departed from the defending ledge almost transversely to the general eastward course of the valley. Consequently the corresponding southern scarp, S′, makes a strong reëntrant on the south side of the valley. The second scarp, K″, of the northern group was more gently curved; the third scarp, K‴, still more gently curved; and the same relation is seen in S″ and S‴. It is possible that even the higher southern reëntrant, S, is indirectly related to the ledges of the northern valley-side about K; the general curvature of the river being determined by the ledges and a southward swing of the curving river there causing the excavation of the reëntrant, S. It is proposed to make a careful measurement of all these terraces in order to test their correspondences.

Another example of this cross-valley relation is found farther west. The curved scarp of the lowest northern terrace, N′, that sweeps out to the defending ledges at M, is the northern member of a double curve whose southern member made the strong concave sweep, P, already mentioned, under the high southern terrace plain. The ledges at M stand unusually

far forward toward the valley axis; this southern sweep is therefore the only one that has consumed all the southern terraces at intermediate and low levels. The abandoned channel of the sweep is still swampy and the enclosing scarp is still uneven with landslides, so lately has the river been withdrawn. It is natural enough that the river should not have swung so far south at higher levels, for the guiding ledge, M, is rather low; it was not encountered until the river had cut down its flood plain nearly to the present level.

Inasmuch as the southern sweeps, S′ and P, seem to have been guided by the northern ledges, K′ and M, it is natural to find the unconsumed remnant of the terrace between the two sweeps in the form of a cusp, Q. This cusp is about forty-five feet high. It is entirely undefended and might, therefore, at first sight be classed with free cusps, and regarded as the consequence of a chance intersection of successive meander sweeps on the valley side. But the dependence of the sweeps, P and S′, upon the defended spurs on the northern side of the valley shows that the strong southern cusp, Q, is not altogether accidental. It is in reality a natural, although an indirect and temporary, product of the northern ledges at M and K′. Unlike the defended northern spurs, which are relatively permanent features, the indirectly defended cusp, Q, will not endure. Its apex is already truncated by a chance swing of the river against it; it will be more and more consumed as such swings are continued and repeated. It is safe only so long as the river flows on curves determined by the ledges at M. and K′.

The truncated free cusp, W, on the south side of the valley, is probably related to Brown's spur, F, in much the same way that the truncated spur, Q, is related to Perry's spur, K′.

Another southern cusp, T, is the remnant of a 15-foot terrace projecting far into the valley between the southern reentrants, T′ and P. A strong scarp, T″, with blunt salients rises to the high plain back of T. The sharp apex of the cusp points directly to the ledges at M, yet it is entirely undefended south of the river. It is probable that there was something of up-valley carving on the eastern side of the cusp; a relatively unusual process, for, as has been stated above, river meanders normally progress down-valley. But in this case, the down-valley progress of a northern meander was stopped by the ledge at M. The ledge probably acted as a sort of fulcrum as soon as the river impinged upon it; the deeper the northern reëntrant, N′, was cut, the more nearly the river must have turned square across the valley at M, and the more it must have been turned against the down-valley side of the spur, T. Something of the same kind probably occurred when the reëntrants, S′, S″, S‴, were scoured out.

14. *Development of future meanders.*—The river is evidently tending to become more curved at its northward bend, L, and its southward bend, Q. It was formerly less curved; and it was probably then that it ran into the strongly concave reëntrant, V′. No immediately local cause is found for the preservation of the low spur, V, for no defending ledge is to be seen at its apex; but one may be there, buried in the flood plain deposits; the sandstone outcrops in the little island near by and in the cusp F nearly opposite. It is possible that these ledges held the river in the channel between them (on the north side of the present island) while the river scoured out the sharply concave reëntrant, V′; and that, as the river increased its curvature at L and Q, it withdrew from the curve of V′. Such a series of changes would not be inconsistent with what is known of the development of river meanders. Their greatest dimensions are attained only where the curves are well organized, and such organization requires time for its accomplishment. A limit is set to the size of the curves, less by an equilibrium between current and bank than by the abandonment of the curves when short cuts and cut-offs are made. The river course is thereby made nearly straight again, after which a new series of curves is gradually established. The Westfield river hereabouts is comparatively straight to-day. Its course for several miles eastward from T must be much less curved now than when the concave terrace fronts were carved at various earlier dates. But a strong curve is seen to-day at T′; the curves at L and Q are increasing and their maximum curvature is not yet reached, and hence it may be expected that another period of organized meandering is approaching. The restraint of the ledges at M will soon be avoided by the down-valley progress of the meander T. The northward curving at L will be resisted by the railroad. The southward curving at Q may be delayed by the abundant fall of gravels from the truncated end of the spur; and indeed there are already some indications that the river may bend southward into the low flood plain west of the spur. A stronger northward turn toward F would thus be induced and a stronger southward turn might then follow farther eastward. The latter item in this series of changes would be made more probable if the swinging river would again pass the ledges at F on a southeastward course, as it did when carving the up-valley side of Brown's spur.

All these details are relatively trifling, yet they have a value in that they unite in showing the competence of ordinary processes, appropriate to a meandering, swinging and slowly degrading river, to produce even the most minute forms of our terraces. There is no demand for an ancient river of great

volume or for repeated movements of uplift in the terrace problem of the Westfield river.

15. *Southern terraces at Westfield.* — Nearer Westfield the complication of the southern terraces increases somewhat, and there is one member of the series at a higher level than elsewhere on the south side of the valley in this district. It may be therefore inferred that the river belt has hereabouts been shifting northward, and this would be confirmed by the high terrace of the opposite northern reëntrant. Yet no ledges are found on the south side of the valley as a cause of this shifting. The only explanation that I have thought of for it is that Little river once entered the Westfield from the south near the present site of Westfield village, and thus slowly pushed the Westfield river northward from the course it had previously followed. Interference of one river with another in this way has been suspected in the eastern basin, beyond Westfield, and in several other localities in the Connecticut valley.

16. *Conclusions.*—The most manifest conclusion to be drawn from this study is the one already announced; namely, that Miller's theory of defending ledges gives a better explanation than any other for the terraces of our New England valleys. It is not desired to imply by this that all our terraces are defended, but that most of them are; and especially that all the many-stepped flights of terraces owe their preservation to defending ledges. Decrease of river volume and intermittent uplifts do not seem to have had any significant part to play in the restriction of the swinging rivers to narrower and narrower belts. Another conclusion is that the normal action of a meandering and swinging river suffices to account for practically all the details of terrace form; and hence that terraces, like other land forms, are susceptible of explanation, even down to their most minute elements. Following this there is a third conclusion, of interest to those who concern themselves especially with the study of land forms; namely, that in this division of the subject as well as elsewhere, observation is greatly aided by the discovery of a successful theory; for the essential facts are then quickly acquired by well directed search. It is also apparent that here as elsewhere description is greatly facilitated by explanation, for explanation enables the student to bring the local example into proper relation to the generalized type. There may seldom be necessity of giving minute description of forms so small and so ephemeral as drift terraces; but when that necessity arises it will be met better by characterizing terraces in terms explanatory of their origin than by an attempt at absolute or empirical description;

the defended and the free cusps, the high scarps without outcropping ledges, the flights of advancing terrace steps in association with groups of outcropping ledges, the correlations of the terraces on the opposite sides of a valley, all these items are best told by explaining them.

Finally it may be noted that even the geologist who is concerned only with the underlying rocks may well afford to give some heed to the pattern of drift terraces; for he will be most quickly guided to his desired outcrops if he examines the points and the up-valley sides of the terrace cusps.

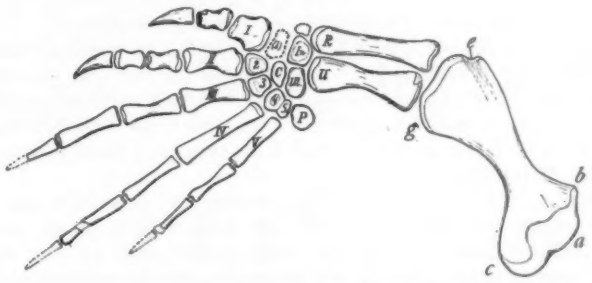
Cambridge, Mass., June, 1902.

ART. XIV.—*Notes on the Cretaceous Turtles, Toxochelys and Archelon, with a Classification of the Marine Testudinata;* by G. R. WIELAND.

I. *The Front Flipper of Toxochelys latiremis.*

A FINE specimen of *Toxochelys latiremis* Cope* from the Niobrara Cretaceous of Kansas (Accession No. 2491 of the Yale coll.) includes a well preserved skull and lower jaw, six cervical, and several dorsal vertebrae, anterior portions of the carapace and plastron, and two nearly complete front flippers. Although some of these bones are somewhat crushed, their preservation is in all other respects exceedingly good. The

Figure 1. *Toxochelys latiremis* Cope. Dorsal view of the left front flipper, x¼.



a, b, c, e, g, respectively the head, radial and ulnar processes, ectepicondylar groove, and entocondyle of the humerus; R, radius; U, ulna; In, intermedium; Ul, ulnare; P, pisiform; C, centrale; 1–5, first–fifth carpalia; I–V, first–fifth metacarpalia.

left of the front flippers is evidently the more complete, and apparently only lacks the radiale, first carpale, and some distal portions of the terminal phalanges of the third, fourth, and fifth digits. The various elements, with the exception of carpalia 4 and 5, were separated in collecting, or else had originally been more or less scattered. Nevertheless, the arrangement of the parts, as shown in figure 1, is given with considerable confidence as to the correctness of the main facts.

Hitherto our knowledge of the front flipper of *Toxochelys* has been limited to the proximal half of the humerus and two fingers as described by Case,† although the phalanges are men-

* E. D. Cope.—Vertebrata of the Cretaceous Formations of the West, vol. ii, Rep. U. S. Geol. Sur. of the Territories. Washington, 1875.

† E. C. Case.—University Geol. Sur. of Kansas, Paleontology, part iv, *Toxochelys*. Topeka, 1898.

tioned as "flattened" by Cope. Case figures as the first finger what is here denoted as the second, but, as is further mentioned below, there is a striking peculiarity in the strong resemblance of the second metacarpal to the first, which would lead one to err in this respect in the absence of the other digits.

Description. The humerus, rather broader in the fossil than in life as the result of crushing, is, as I have already pointed out on the basis of the proximal portion only, of the *thalassoid* type characteristic of various of the older Chelonidæ.* That is, while the general outline closely approaches that seen in typical oceanic turtles, certain persisting older characters are present, such in particular as the high position of the rather prominent radial crest. The most closely related humeral form is to be seen in *Lytoloma*† and in *Neptunochelys tuberosa* (Leidy, Cope) Wieland.*

The radius is somewhat longer than the ulna as in other Chelonidan forms, and also be it noted as in *Acichelys* (*Eurysternum*) *Wagleri.* (See figure in Zittel's Handbuch.)

The large *intermedium* is also of the same general outline as that of *Acichelys.*‡ The arrangement of the carpals is, however, mainly as in *Chelone*, etc., the first carpale not being excluded from contact with the centrale, while the first metacarpal is set high, and the small and thin *pisiform* is attached to the fifth carpale.

General Observations. The present is probably the first fairly complete restoration of the fore flipper of an ancient marine Chelonian which has been given, and as one might well expect in the case of a Cretaceous turtle presenting various primitive characters, no little light is shed upon the manner in which the evolution of the Testudinate flipper has proceeded. The most striking peculiarity is the flatness of metacarpal II. This bone presents characters distinctly intermediate to those of metacarpals I and III. As flattening is usually only present in the bones of the first finger, there is in *Toxochelys* a very marked use made of this means of adaptation for marine life. *Toxochelys* has two well developed claws, not noticeably differing in this respect from *Eretmochelys*, but the short and robust phalanges of the first and second fingers, all of which are exceedingly well preserved, are decidedly more suggestive of those seen in land forms than in the case of any other known distinctly marine turtle.

* G. R. Wieland.—Some Observations on Certain Well-marked Stages in the Evolution of the Testudinate Humerus. This Journal, fourth series, vol. ix, June 1900.

† L. Dollo.—On the Humerus of *Euclastes.* Geol. Mag., vol. v, pp. 261–267. London, 1888.

‡ Zittel.—Handbuch der Paleontologie.

With respect to the distal phalanges of the fourth and fifth fingers, it should be stated that the present restoration is of necessity more or less generalized. These phalanges being more slender than those of the first and second fingers, have suffered crushing, and having been isolated also, one cannot be wholly sure of their exact order. Nevertheless, it is fully evident that fingers 3–5 are long, and have the structure seen in strictly marine turtles. In the appended table of measurements only those elements are given which may be determined with reasonable certainty, though the estimated lengths of fingers 3–5 are doubtless very near the truth.

At least we are enabled to deduce the principal variants in the evolution of the Testudinate flipper from some generalized type of foot like that of *Chelydra*. The humeral changes in general form I have already outlined at some length. In the case of the remaining elements it would of course be desirable to consider an approximately phyletic series, but in the absence of this, the general trend of change may best be made clear by considering the percentage of length of the elements of the flipper in *Chelydra*, *Toxochelys*, *Eretmochelys* and *Dermochelys*. These are, together with *Acichelys* of the Jurassic, and the known portions of *Archelon*, as follows:

	Humerus.	Radius.	Ulna.	1st finger.	" 2nd	" 3rd	" 4th	" 5th	Pisiform.
Dermochelys,	100	43	39	127	180	209	173	86	23
Eretmochelys,	100	53	44	49	89	128	105	44	12
Archelon,	100	54	51	—	—	—	—	—	21
Toxochelys,	100	58	50	51	73	100±	104±	70±	11
Chelydra,	100	52	53	50	72	73	55	50	(small)
Acichelys (=Eurysternum),	100	57	51	40	54	63	66	51	17

Inspection of the above table shows:

1. Strongly marked radial and ulnar decrease in length.

2. Greater or less elongation of the radius as compared with the ulna.

3. Nearly static length of the first finger in the Chelonidan forms, with sharp increase in Dermochelys.

4. Persistent increase in the length of fingers 2–4.

5. More or less variable tendency to increase in length of the fifth finger.

6. Great pisiform increase, which began relatively early.

Measurements of Toxochelys latiremis.

(All are from the same individual.)

The Skull.

	M.
Extreme length from beak to extremity of the supra-occipital process, which is complete	·152
Length from beak to occipital condyle	·114
Extreme width	·11
Width between articular surface of quadrates	·078
Length from beak to anterior border of internal nares	·025
Extreme length of ramus of lower jaw	·11

The Cervicals.

Length of 1st cervical centrum	·014
Length of 2d " "	·025
Length of 3d " "	—
Length of 4th " "	·033
Length of 5th " "	—
Length of 6th " "	·032
Length of 7th " "	·031
Length of 8th " "	·03
Estimated total length of the eight cervicals	·226
Length of 1st dorsal centrum	·023

The Humerus.

	M.
Greatest length	·135
Depression of radial crest beneath proximal extremity	·02
Distance of ectepicondylar groove from distal anterior border	.005

Greatest length of the other elements of the front flipper:

Radius	·075	Metacarpale, III	·039
Ulna	·066	" IV	·055
Intermedium	·018	" V	·037
Ulnare	·017	Phalanx, I–1	·018
Centrale	·015	" I–2 (claw)	·024
Carpale I	—	" II–1	·02
" II	·015	" II–2	·019
" III	·013	" II–3 (claw)	·025
" IV	·013	Phalanx III–1	·034
" V	·011	" III–2	·039
Pisiform	·015	" IV–1	·036
Metacarpale, I	·023	" V–1	·031
" II	·035		

Total length, first finger	·65
" " second finger	·095
Estimated length, third finger	·13
" " fourth finger	·135
" " fifth finger	·09

II. *The Front Flipper of Archelon ischyros.*

In my first description of the gigantic turtle skeleton from the Fort Pierre Cretaceous of South Dakota which constitutes the type of *Archelon ischyros*,* I figured, in addition to other skeletal parts, the humerus, radius, ulna, femur, tibia, and fibula, and mentioned the fact that a number of carpals and tarsals with several phalanges were also present. This was practically the first contribution presenting the main features in the limb organization of the [Protosteginæ]. Hitherto our knowledge of the flippers of these great turtles had been limited solely to that given in Cope's original description of the first member of the group discovered, *Protostega gigas*.† In this form the humerus was described and figured together with the radius and ulna, although the latter were then supposed to be "metapodials" rather than bones of the forearm.

As there was at the time of my first publication an absolute dearth of information concerning the carpal and tarsal structure in marine turtles from the American Cretaceous, not one having been described, the fear that I might make some serious error prevented my publishing the restoration of the carpus which I then made, the various elements having been found only partly in position.

Now, however, Professor Williston‡ has just described the hind flipper of *Protostega*, and this enables me by exclusion to determine with a reasonable assurance of correctness that the elements I originally assigned to the carpus in my study of the closely related *Archelon* truly belong there. I am hence able to add some further facts concerning the skeletal organization and systematic position of these highly interesting Testudinates.

The partial restoration of the left fore flipper shown in figure 2 is based on the radius and ulna, with what are considered to be all of the carpals but two, together with the first and fifth metacarpals. Several phalanges are present, but as finger proportions may vary markedly it is not deemed advisable to attempt a complete restoration. The value to be attached to this preliminary restoration is provisional, as follows:

(a) The radius and ulna are simply drawn in a generalized position, but their orientation is based on that found in a second specimen where these bones were in an approximately normal position with respect to the humerus, only.

* G. R. Wieland.—A New Gigantic Cryptodire Testudinate from the Fort Pierre Cretaceous of South Dakota. This Journal, fourth series, vol. ii, December 1896.

† Loc. cit.

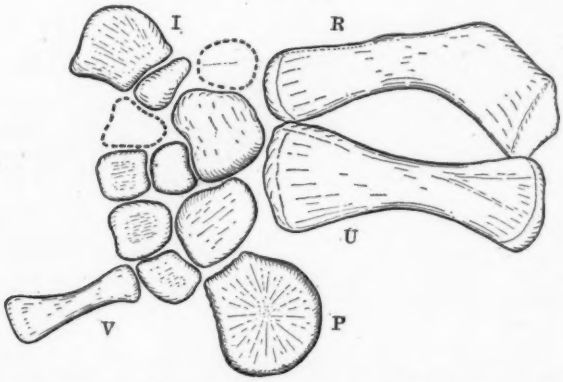
‡ S. W. Williston.—On the Hind Limb of *Protostega*. This Journal, fourth series, vol. xiii, April, 1902.

(b) Carpalia 3–5 were found in succession, and are doubtless correctly placed.

(c) There is little doubt but that the intermedium and ulnare are correctly determined, but their precise orientation is not so certain. Thus it may be that the intermedium should be rotated in a vertical arc of 90°. This, however, would not greatly alter its general contact outline, as it is a very robust and much rounded instead of flattened bone.

(d) Since metacarpal I and the pisiform are beautifully preserved, both as to form and surface markings, the possible remaining margin of error as to the identity of the several parts is slight.

Figure 2. *Archelon ischyros* Wieland. Partial restoration of left front flipper, x1/8.



R, radius; U, ulna; P, pisiform; I, carpale 1; V, carpale 5.

Description. Since the peculiarities of the *humerus* have been quite fully dealt with in my article on the Evolution of the Testudinate Humerus, this bone need not be further mentioned now, except to recall the fact that it resembles the humerus of *Dermochelys* more closely than any other, although differing in some very essential features.

The *radius* is only slightly longer than the ulna. Proximally it is triangular, and distally, rather elliptical in transverse section. The most marked characteristic whatsoever is the strong proximal bow, which recalls the lesser proximal bow seen in the radius of *Dermochelys*. Otherwise this form has a rounder, heavier head. The proximal articular face is only slightly concave, its general outline being that of an isosceles triangle, with the base in contact with the inner face of the ulna.

The *ulna* is short and massive. The proximal articular surface is slightly crescentic in general outline, and somewhat concave except for an oblique, low, saddle-shaped ridge which divides this face into subequal areas, the larger facing towards the radius. The distal articular surface is moderately convex antero-posteriorly, and rather flat in the dorso-ventral direction. The bone has a distinct broad and shallow grooving on the proximal ventral, and on the distal anterior side, marking the proximal and distal contact with the radius and producing the effect of a marked twist corresponding to the high angle between the general trend of the proximal and distal articular faces. As in the case of the humerus and radius, there is a certain correspondence with *Dermochelys*, but the ulna of the latter is more rounded.

The *intermedium* is much rounded and very robust. The *ulnare* is suboval in external outline, with the proximal edge much the thicker. The *pisiform* is very large, of subcrescentic outline, thick, and quite flat, but with a raised border on both faces.

The carpalia and metacarpals present have more the appearance seen in the Cheloninæ than in *Dermochelys*, in which respect there is in fact a wide difference, the pronouncedly marine appearance of the rounded subcylindrical and flat-ended metacarpal and phalangal bones of the latter being quite absent.

General Resemblances. In so far as now known, the manus and pes of *Protostega* and *Archelon* resemble those of *Dermochelys* rather more than any other form. Briefly pointed out, the more marked similarities of the manus are, the approximately equal length of the radius and ulna, the heavy proximal bow of the radius, the carpal organization with the centrale excluded from contact with carpale 1, and an enormous pisiform set high up near the ulna, and mainly on the ulnare. The point of most importance and necessarily of the greatest difficulty to settle with complete satisfaction is as to the assumed contact of the centrale with carpale I.

Professor Williston has, I think, omitted one of the tarsalia from his restoration of the hind limb of *Protostega*, so that there is likewise an even closer general correspondence between the hind limbs of these several forms than he suggests. The diminution of the fifth finger of the hind flipper, as he shows, to a single metatarsal is, I suppose, not to be regarded of as much importance as any reorganization of the carpalia or tarsalia (loc. cit.).

Measurements of Archelon ischyros.

(From the type specimen.)

The Radius.

	Meters.
Length	·35
Proximal diameters	·082 and ·114
Least diameters of shaft	·05 and ·067
Distal diameters	·049 and ·114

The Ulna.

Length	·33
Greatest and least proximal diameters	·093 and ·14
" " " diameters of shaft	·054 and ·063
" " " distal diameters	·088 and ·138

Measurements of carpals and metacarpals, viewed from dorsal surfaces:

	Greatest length.	Greatest width.
Intermedium	·8	·11
Ulnare	·11	·08
Pisiform	·14	·12
Centrale	·048	·06
Carpale I.	·04	·07
" II.	—	—
" III.	·06	·056
" IV.	·068	·068
" V.	·06	·072
Metacarpale I.	·09	·10
" V.	·156	·056

The extreme length of the accompanying humerus is ·65 meters.

III. *The Cervicals of Toxochelys and Archelon.*

(See Measurements, p. 98.)

The cervical formula has not hitherto been given for any of the Cretaceous marine turtles, so far as the writer is aware, our knowledge having been restricted to scattering or isolated vertebræ. I may hence give the formula for *Toxochelys*, and will show that that of *Archelon* may also be determined as quite similar, since we know the vertebræ most susceptible of change, the last three.

In the Yale specimen of *Toxochelys* (see Measurements), the first, second, fourth, sixth, seventh, and eighth cervical vertebræ are present. The nature of the other two, the third and the fifth, of course follows, as included arbitrarily in the subjoined table, in which are given the formulæ for the present forms and several others presenting interesting or im-

Cervical.	I *Archelon ischyros.*	II *Toxochelys latiremis.*	III *Dermochelys coriaceæ.*	IV *Eretmochelys imbricata.*	V *Chelydra serpentina.*	VI *Testudo polyphemus.*	VII *Erymnochelys Madagascariensis* (Grand).	VIII *Podocnemis Dumerilianus.*	IX. *Trionyx spinifer.*
1	Complex	Complex	Complex	Complex	Complex	Complex	Complex	Complex	Complex
2	Cyrtocœlian	Cyrtocœlian	Cyrtocœlian	Cyrtocœlian	Cyrtocœlian	Cyrtocœlian	Cyrtean	Cyrtean	Cyrtocœlian
3	"	"	"	"	"	"	Cœlocyrtean	Ephippic	"
4	Cyrtean	Cyrtean	Cyrtean	Cyrtean	Cyrtean	Cyrtean	"	"	"
5	Cœlocyrtean	Cœlocyrtean	Cœlocyrtean	Cœlocyrtean	Cœlocyrtean	Cœlocyrtean	"	"	"
6	"	"	"	Cœloplatyan	Cœlo-bicyrtean	Cœlo-bicyrtean	"	"	"
7	"	"	Cœlo-bicyrtean	Platy-bicyrtean	Bicœlo-bicyrtean	Bicœlo-bicœlian	"	Cœlocyrtean	Cyrto-bicœlian
8	"	"	Bicœlo-cyrtean	Bicœlo-cyrtean	Bicœlo-cyrtean	Bicyrto-bicyrtean	"	"	Bicyrto-cyrtean

1. Cyrtean = double-convex; Cœlian = double-concave; Bicœlo-bicyrtean = doubly concave anteriorly, and doubly convex posteriorly, and so on. See this Journal for August, 1899, p. 163.
2. The last cervicals of *Toxochelys* are broad, but do not actually develop into double-concave, double-convex, or flatly terminated centra.
3. No. 7 of *Dermochelys* approaches platybicyrtean as in *Eretmochelys*.
4. The third–sixth cervicals of *Podocnemis* are quite as distinctly saddle-shaped as those of birds, doubtless as the result of the habit of retracting the neck laterally.

portant comparisons. All taken together display the great variations seen in particular in the last five Testudinate cervicals. I may explain that I have introduced a modified nomenclature I proposed in this Journal for August, 1899, p. 163, since the ordinary and incomplete terminology does not adequately express the complicated forms seen in Testudinate cervicals.

The cervicals of *Toxochelys* are distinctly intermediate in character between those of *Chelydra* and the *Chelonidæ*, being most like the former. The ends of the sixth, seventh and eighth broaden, but there are no distinctly biconcave, biconvex, or flat terminations, these vertebra still being procœlous (cœlocyrtean). Their centra have strongly marked elongate and thin or blade-like keels, quite similar to those of the sixth and seventh, but not the eighth centrum, of *Chelydra*. The total length falls far short of that seen in the *Chelydridæ*.

In *Archelon*, the sixth, seventh and eighth cervicals were found in place in the type specimen, as well as several others. All are characteristically procœlous (=cœlocyrtean), and none have their anterior ends markedly broadened as in *Toxochelys*. They are also relatively much shorter than in *Toxochelys*, and very robust (loc. cit.). I have estimated the cervicals of the type specimen of *Archelon* as having a length of ·72^{m}. The cranial length must be about the same. But in *Toxochelys* the total length of the cervicals is about one and a half times, and in *Chelydra* twice that of the cranium. We cannot doubt that the fourth cervical was biconvex (Cyrtean), since it is so in all known marine Testudinates. The vertebræ of *Archelon* are on the whole rather more primitive than in any other marine turtle, and it is certainly very interesting that there should be a closer agreement with *Toxochelys* than any other form.

IV. *Bearing of the Foregoing Data, and Classification.*

A phylogenetic classification of the marine Testudinates will still be held more or less difficult to deduce, according to the view that is taken of the much debated descent of *Dermochelys*. In weighing the evidence at present available, however, it needs to be borne in mind that the wide distribution of the turtles in latitude and time necessitates the consideration of slighter differences than in the case of more variant forms. While this must finally be a great advantage, it is a fact that at present brings home to us with force our imperfect, but happily rapidly increasing, knowledge of the fossil record. Again, there is a constant danger that in such a case one may regard evolution as having taken a far simpler course than has

really been the fact. It would appear that several hypotheses yet require consideration, as follows:

(1) All the known marine Testudinates may be the descendants of a single littoral species.

(2) *Dermochelys* on the one hand, and all the other marine forms on the other hand, may have descended from two different littoral species of the same genus, or from different genera.

(3) *Dermochelys*, *Toxochelys*, *Protostega*, and the living *Chelonidæ* may represent the descendants of four genera of the same, or closely allied families.

(4) *Dermochelys* is of ancient descent, and stands phyletically and morphologically opposed to all other Testudinates.

Doubtless the final truth will be found to lie somewhere between the first and last extremes. Certainly it is difficult to overthrow the conclusion as to the general fact of descent as thus expressed and as defended with such signal ability by Baur:*

"Darüber aber ist kein Zweifel dass *Dermochelys* und *Psephophorous* keine urspünglichen Formen sind, sondern dass sie von wahren 'Thecophoren' und zwar von den 'Pinnaten' abstammen, um mich hier dieses Ausdrucks zu bedienen."

Dollo,† originally a strenuous opponent of this view, has recently adopted it. Taking up the question in further detail, he holds *Dermochelys* to be descended from a pelagic Thecophore with an extremely reduced carapace and plastron, but the descendant of a littoral Thecophore with a fully developed carapace, and a plastron without fontanelles. And this eminent scientist has proposed the ingenious hypothesis that such a Thecophore again acquired littoral habits, résulting in the formation of a heavy mosaic carapace, which, with a second resumption of pelagic habits, again began to disappear, and is still in process of reduction. The persistence of the nuchal is held to be due to its value as an attachment for the nuchal ligaments. However involved such an evolutionary process may appear, it is skilfully presented, and has much in its favor.

On the other hand, Hay‡ has presented at considerable length facts favoring a very early origin of the Dermochelan line.

* G. Baur.—Biologisches Centralblatt, Band ix, 1889, p. 191 (Erlangen).

† L. Dollo.—Sur l'origine de la Tortue Luth (*Dermochelys coriaceæ*). Extrait, Bull. Soc. roy. des Sciences Med. et Nat. de Bruxelles, Seance 4 fevrier, 1901.

‡ O. P. Hay.—On Protostega, the Systematic Position of *Dermochelys*, and the Morphogeny of the Chelonian Carapace and Plastron. American Naturalist (Boston), Dec. 1898.

Presumably the evidence in favor of Baur's view is increasing. The writer so regards it. The fact that the cervicals of *Toxochelys* and *Archelon* agree in general, and at the same time differ most widely from the cervicals of *Dermochelys* and of the Cheloninæ, is, however, rather unexpected. Did the vertebræ of these Cretaceous forms tend to simplify, or has there been a more or less remote homoplastic parallelism in the course of complication in the case of the sixth, seventh and eighth vertebræ of the modern sea turtles, and such widely different forms, for instance, as the Testudinidæ?

The question at once arises, what is to be regarded as a very primitive Testudinate cervical, and what was the form in the species, genus, or group which made its way into the sea and gave rise to the marine group? We may most reasonably suggest as a very primitive cervical type, that of a turtle like the Pleurodiran *Erymnochelys*, in which there is a well-nigh complete agreement with the modern *Crocodilia*, the second, and not the fourth, centrum being biconvex. And we assume that some descendant of such a primitive type, with double convexity moved back to the fourth cervical centrum, the fifth–eighth centra remaining simply procœlous, stood in some common ancestral relationship to the sea turtles and most other existing Cryptodirans. It would at present, therefore, seem that even since the sea turtles split off from their littoral ancestry there has been a certain parallelism in the secondary cervical modifications undergone by them and the most nearly related land forms. This may hence prove, once we know the record more completely, to be another example of the fact that a course of evolution and change once established in a persistent group, may long continue, after the invasion of wholly new environments. There is in biologic, as in physical evolution, inertia.

As to the carpus of *Archelon*. It will certainly be very interesting if my surmise that there is no union between carpale 1 and the centrale should prove correct. This, although to be regarded as a secondarily acquired character, would indeed go far toward narrowing the gap between the extreme ends of the marine group. I may point out that the greatly accentuated bow of the radius of *Archelon* would make it probable, even in the absence of more direct evidence, that there was present some marked change in the order of the carpals.

Systematic Position of Archelon. While the data given in the preceding notes go far towards showing that *Protostega* and *Archelon* present more osteological resemblances to *Dermochelys* than any other turtles whatsoever, living or extinct, their structure is essentially that of the Chelonidae, of which

they may best be regarded as a subfamily, the Protosteginæ. Moreover, these Dermochelan resemblances are only what we might well expect in Cretaceous turtles. There are likewise, as we see, certain Chelydran resemblances in the general type of skull, just as there are also Chelydran resemblances in *Toxochelys*. We are simply following convergent lines back sufficiently far to somewhat accentuate general relationships.

Position of Toxochelys. The fore flipper and cervicals of *Toxochelys* present some additional Chelydroid characters to those of the cranium and lower jaw, as already pointed out by Cope and Hay. *Toxochelys* hence proves to be one of the most interesting of turtles. Like *Protostega* and *Archelon*, it points with more or less distinctness toward a Chelydra-like ancestry. Baur has said that this genus should be placed in a distinct family, and in this has been followed by Hay and Case. But I think that *Toxochelys* may more conveniently be considered as representing a subfamily of the Chelonidæ, certainly if of common ancestry.

V. *Provisional classification of the marine Testudinates.*

Chelonioidea (Baur).

(Superfamily of the Cryptodira.)

A parieto-squamosal arch; palatine foramen and free nasals sometimes present (Desmatochelydinæ); fourth cervical biconvex, with the centra of the sixth, seventh, and eighth usually greatly modified.

I. *Dermochelydidæ.*

No descending parietal processes; no palatine foramen; other cranial and limb characters not remote from those of the Chelonidæ; carapace represented by the nuchal only, and body enveloped in a leathery hide with an osteodermal mosaic; no claws. Genera: *Dermochelys*, *Psephophorous*, *Eosphargis*.

II. *Chelonidæ.*

Skull with descending processes of parietals, so far as known; palatine foramen sometimes present; vomero-premaxillar union often, but not constantly present; a normal, though often much reduced, carapace and plastron; nuchal with or without process on under side; claws, one or two.

1. Protosteginæ.—No free nasals; no palatine foramina; obturator foramen small and enclosed by ischiopubic contact on median line, as in many land forms.

Genera: *Protostega* and *Archelon*; *Protosphargis*? *Pseudosphargis*?

2. Toxochelydinæ. — No free nasals; palatine foramen, pterygoids, and lower jaw distinctly Chelydra-like; two strong claws.

Genera: *Toxochelys*, *Porthochelys*, *Cynocercus* (?), all of the Niobrara Cretaceous of Kansas, also *Neptunochelys* from the Cretaceous of Mississippi.

3. Desmatochelydinæ.—Free nasals; distinct palatine foramina (except *Rhinochelys*?).

Genera: *Desmatochelys*, *Rhinochelys*, *Atlantochelys*.

4. Cheloninæ.—No free nasals; no palatine foramina; vomero-premaxillar union often, but not constantly present; obturator foramen presumably not enclosed as in *Archelon* in any member of the group; claws, one or two.

Genera: *Osteopygis*, *Allopleuron*, *Lytoloma*, *Argillochelys*, *Eretmochelys*, *Chelone*, *Colpochelys*, *Thalassochelys*.

* * * * * *

Resume.—In the foregoing notes the following additions to the osteology of the marine Testudinates have been made:—

1. The elements and organization of the front flipper of *Toxochelys*.

2. The main elements of the wrist region of the front flipper of *Archelon ischyros*. (These are described from the type of the genus and species. The writer, in his first announcement of the discovery of this gigantic turtle, figured and described the accompanying humerus, with the radius and ulna, as well as the femur, tibia, and fibula,—this being the first instance in which all these limb bones were made known in the case of any extinct marine Testudinate.)

3. Important measurements for the coördination of various skeletal elements of *Toxochelys* and *Archelon*.

4. The deduction (with the exception of the secondary rearrangements of the carpals) of the principal lines of change in the evolution of the fore flipper from the foot of some primitive swamp, or littoral, *Chelydra*-like turtle.

5. The cervical organization of *Toxochelys* and *Archelon*, which is compared with that of living turtles.

6. A classification of the marine turtles.—This has chiefly been made possible by the description during the last few years of large portions of the skeleton of *Protostega* and of *Toxochelys*, and especially by the discovery of *Desmatochelys*, *Archelon*, and *Porthochelys*.

Yale Museum, New Haven, Conn.
April, 1902.

Art. XV.—*The Magnetic Effect of Electric Displacement;* by John B. Whitehead, Jr.

Historical Review.

In the development of his theory of the electromagnetic field, Maxwell assumes that the phenomenon of polarization in a dielectric consists of an actual propagation or displacement of charge in the direction of the polarization; that in the case of the charging of a condenser, for instance, this act of displacement is equivalent to a current at any instant equal to the rate of change of the surface charge on one of the plates, i. e. $q=\frac{K}{4\pi}\frac{dF}{dt}$, q being the current density, K the specific inductive capacity and F the difference in potential per unit length, and that therefore the current is continuous throughout the circuit. He assumes further that the displacement current has the same magnetic effect as would be produced by a conduction current of density $q=\frac{K}{4\pi}\frac{dF}{dt}$, so that in the case of the condenser the magnetic effect in the neighborhood, incident upon any change of charge, would be due to the combined influence of the current in the charging wires and the displacement current in the dielectric.* "It appears, therefore, that at the same time that a quantity Q of electricity is being transferred along the wire by the electromotive force from B towards A, so as to cross every section of the wire, the same quantity of electricity crosses every section of the dielectric from A towards B by reason of the electric displacement." (Art. 60.) . . . . . .

"The variations of the electric displacement evidently constitute electric currents." (Art. 60.) . . . . . .

"One of the chief peculiarities of this treatise is the doctrine which it asserts, that the true electric current C, that on which the electromagnetic phenomena depend, is not the same thing as K, the current of conduction, but that the time variation of D, the electric displacement, must be taken into account in estimating the total movement of electricity." (Art. 610.)

The remarkable consequences of Maxwell's theory seem to justify his assumptions beyond all question. There need only be mentioned the finite velocity of propagation of electric and magnetic actions, this velocity being the same as that of light; the electromagnetic theory of light, which accounts for the results of experiment, practically without exception; the

* Maxwell: Electricity and Magnetism, Art. 60, 75, 76, 111, 328–334, 608, 783, 791.

experiments of Hertz on electric waves showing them to be identical in behavior with light waves. The direct magnetic effect of the displacement current, however, has never been satisfactorily observed, if at all; published accounts of work in this direction seem to be limited to those of Röntgen, S. P. Thompson, Nicolaieff and Blondlot.

Röntgen.—The earliest attempt, apparently, was that of Röntgen in 1885.* He rotated a rubber disc between two stationary glass plates all in horizontal planes. The upper plate was coated with tin-foil which was grounded; the lower plate had on it a ring of tin-foil which was split along a diameter and the two halves oppositely charged. As the disc rotated there was a change in polarization at those portions of it passing over the opening in the tin-foil, and the resulting displacement current was in opposite directions at the two ends of this opening. Over the whole system and as close as possible to the upper plate, he suspended an astatic needle whose direction was along the line of the opening in the tin foil, and the line of suspension the continuation of that of the axis of the rotating disc. The length of the lower needle brought its ends to the center of the width of the tin-foil rings; any magnetic effect of the displacement current would thus tend to deflect the astatic system. On commutating the charges on the rings the deflection read by a mirror and scale was never over $1{\cdot}5^{mm}$, and the needle was subject to an oscillation of that amount due to disturbing influences. The observer, being ignorant of the direction of commutation, was supposed to take into account the motion already possessed by the needle in giving the direction of the resulting impulse. Röntgen states that after 1000 observations he acquired such practice as to be able to observe the proper direction nearly every time.

The results of this work can hardly be considered conclusive. That little importance is to be credited to it is evidenced by the small notice it has attracted. The genuineness of the observed deflection is particularly to be questioned in view of the fact that the poles of the needle were not in proper position to experience the full magnetic force of the displacement current. Each pole was entirely above the plane of the surface of the dielectric, and it may well be questioned what is the distribution of the magnetic field beyond the terminating surface of an "open current."

Thompson.—In 1889 S. P. Thompson† wound an iron ring with many turns of fine wire and imbedded it in a block of paraffin having on two sides parallel to the plane of the ring

*Rep. der Physik, No. 21, 1885, p. 521.
† Proc. Roy. Soc., xlv, p. 392, 1889.

metal coatings which were connected to an induction coil. The winding on the ring being connected to a telephone receiver, sounds were obtained on charge and discharge of the coil. Very slight conductivity in the paraffin would have caused this.

Nicolaieff.—Nicolaieff in 1895* suspended a ring of paraffin between the two poles of an electromagnet, the plane of the ring being vertical and making an angle of 45° with the axis of the poles. The E.M.F. induced in the ring when the magnet is excited by an alternating current, sets up a displacement current which, by its magnetic reaction on the exciting field, creates a couple tending to make the ring turn and set itself perpendicular to the field. He excited the magnet first with direct current, getting a deflection due to the magnetic qualities of the ring, then with alternating current of the same intensity, causing a different deflection, the difference being due to the displacement current. The record of observations is not given in the paper, the author simply stating that the deflection was greater when the magnetic field was alternating than when direct; and was greater the greater the frequency. For 12 cycles per sec. the increase was 9% over the constant magnetic field, for 15 cycles 12%; in this case also conduction would cause the observed effect.

Blondlot.—Recently M. R. Blondlot† looked for an electric displacement in a mass of air moving in a magnetic field. He forced a blast of air through a rectangular passage, two sides of which were pole faces of a magnet, the other two a pair of condenser plates. The plates were connected by a wire which was broken at the instant the blast was at its maximum, so that the plates should be left charged if there was any electric displacement in the mass of air. He calculated the expected effect and calibrated his electrometer to read it; the results of a number of experiments were invariably negative. Making use of this experimental fact, he then proves theoretically the absence of any electromagnetic action of a magnetic field on a displacement current.

Present Research.

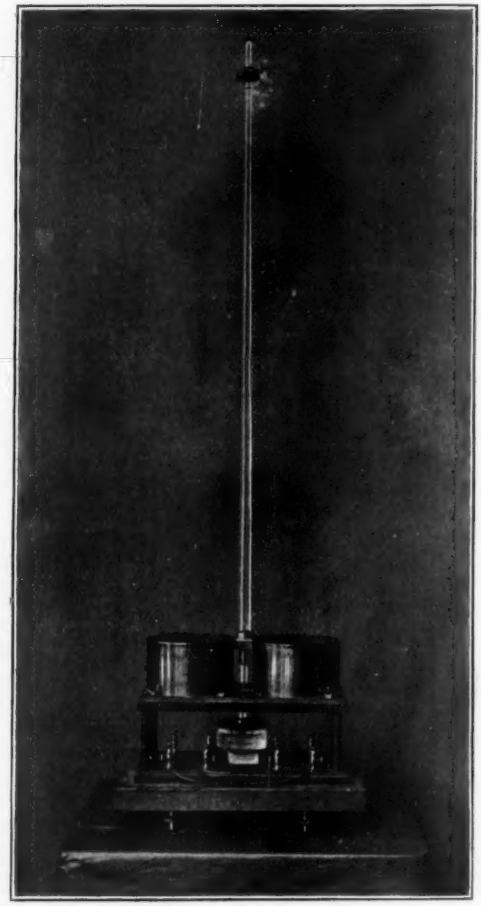
General Theory.

The series of experiments herein described were undertaken in view of the continued uncertainty of the results of all effort to observe the magnetic effect of electric displacement, and in view of the fact that the method employed had certain advantages over those used heretofore.

* Jour. Phys., vol. iv, 1895, pp. 245–254.
† Jour. Phys., Jan. 1902, p. 8.

In principle, the method is to subject a piece of dielectric to an alternating electric field and also to an alternating magnetic field, the directions of the two being at right angles in space; to adjust the phases of the two to give the maximum effect of

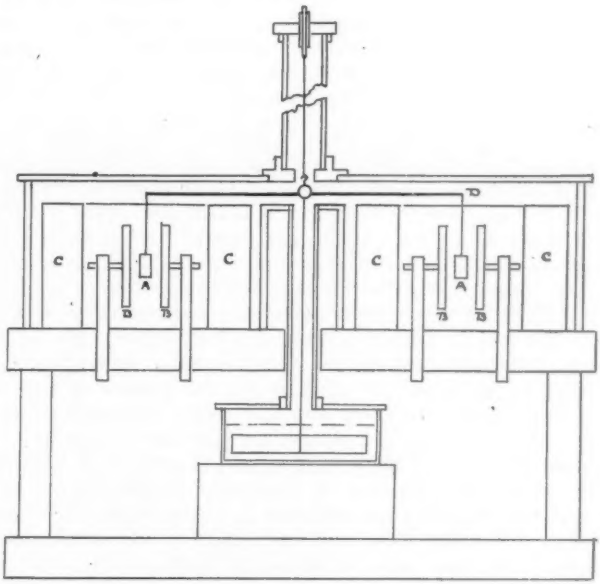
1

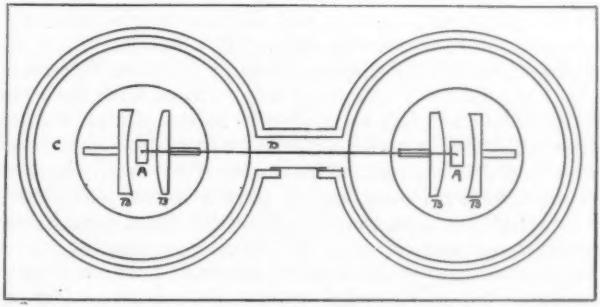


the displacement current reaction against the magnetic field, and to look for motion of the dielectric in a direction perpendicular to the plane including the directions of the electric and magnetic fields. In this form the idea was suggested to the

writer by Professor Rowland shortly before his death. Some twelve years before he made the same suggestion to Dr. Louis Duncan, who constructed a crude form of apparatus, but

2





abandoned the work on account of the difficulty of obtaining a uniform field.

In each of four modifications of the form of the apparatus embodying the above principle, a block of dielectric was hung

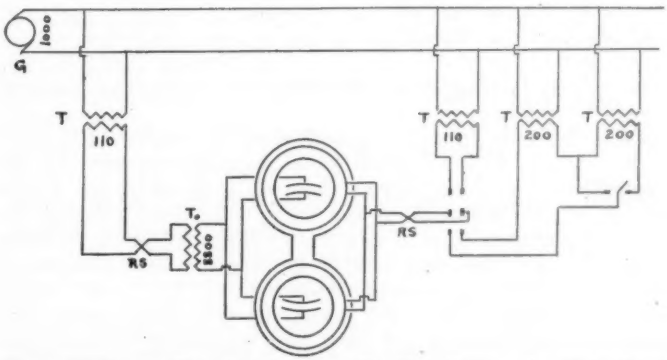
rigidly at each end of a light beam which was suspended horizontally on a quartz fiber attached at its center. The phase of either the electric or the magnetic field on one block being 180° from that on the other, the other field having the same phase for each block, the reaction of the displacement current on the magnetic field would be opposite at the two ends of the beam, causing a couple to act on the fiber suspension.

Apparatus.

First form.—The first form of the apparatus is shown in fig. 1, and fig. 2 gives a central section. A A are the rectangular blocks of dielectric, each attached to the beam D, which was constructed of bamboo or glass; B B B B are brass electrodes each turned so that its surface is a part of a circular cylinder with its axis coincident with the line of suspension of the beam; this was thought to give the best approximation to a uniform electric field between the electrodes. Each pair of electrodes was connected to the terminals of a transformer giving 8800 volts at 133 cycles per sec. C C are circular coils of wire, one surrounding each pair of electrodes, the planes of the turns being horizontal; they are supplied with alternating current from the same generator which excites the electrodes. The magnetic field is seen to be vertical, the electric field horizontal, so the resulting deflection of the beam should be out of the plane of the paper at one end and in at the other. The whole rested on a wooden base, and each half of the apparatus was enclosed in a brass case, there being between the two only a small connecting trough in which the beam could swing, thus making the interior as small as possible and so minimizing the disturbance due to air currents. A close fitting brass cylinder inside the coil, a ring on top, and tin foil on the floor, all connected to the case, which was grounded, protected the dielectric from any electric field due to the coil; all possible secondary circuits were split, the openings being closed with hard rubber or fibre. The damping vane shown in the sketch was a strip of mica immersed in water, attached to the deflecting beam by means of a fine glass rod. The quartz fiber used was approximately 102^{cm} (40″) long in all cases; it was enclosed in a glass tube fitted with a convenient torsion head permitting the adjustments of torsion and length independently; the fibre carried a small copper hook at its lower end which fitted into a corresponding hook sealed to the glass beam. Deflections of the beam were observed by means of the movements on a ground glass scale of the image of an incandescent lamp filament reflected from a small mirror on the center of the beam; during the later experiments the lamp was replaced by a Nernst

filament, which is beautifully adapted to this purpose. The distance of the scale from the mirror was 140^{cm}. The connections are shown in fig. 3. The generator, G, was a Westinghouse "smooth-body," giving a pure sine wave, 1000 volts, 133 cycles; the transformers, T, T, T, were all Westinghouse make. The transformer T_o, giving the high voltage, was built privately; it was of closed magnetic type and had a ratio of 1 to 80. By a suitable arrangement of switches 110, 200, or 400 volts could be put on the coils. The two magnetizing coils were connected in multiple and so that they worked together; i. e., at any instant the fields were equal, parallel, and in the same direction. The electrodes were also in multiple, but worked in opposite directions, i. e., at any instant the fields

3



were equal, parallel, but in opposite directions. In each circuit there was a reversing switch, R S.

Calculation of Effect Expected.—Following is a calculation of the magnitude of the effect in the apparatus as constructed and experimented upon.

Each pair of electrodes were 1·9^{cm} apart; the dielectrics were blocks of rock salt, glass or paraffin, 1^{cm} × 1^{cm} × ·63^{cm} and they were hung with their square faces parallel to the electrodes, so that one-third the length of a line of force was within the dielectric; thus $\sqrt{2}$·8800 being the maximum E.M.F. between the electrodes the proportion of it active on the dielectric is given by:

$$V = \frac{\sqrt{2} \cdot 8800}{2K+1}$$

the intensity of E.M.F. $F_m = \frac{dV}{dl}$

$$F_m = \frac{\sqrt{2} \cdot 8800}{(2K+1) \times \cdot 63} \quad \text{(maximum value in volts).}$$

The density of the displacement current is $q = \frac{K}{4\pi}\frac{dF}{dt}$; since the E.M.F. is alternating we have:

$$F = F_m \sin \alpha$$

and $$q = \frac{K}{4\pi} F_m \cos \alpha \frac{d\alpha}{dt}$$

also, $\frac{d\alpha}{dt}$ = angular velocity $= 2\pi N = \pi \cdot 133$

$$\therefore q = \frac{K}{4\pi} \cdot \frac{\sqrt{2} \cdot 8800}{(2K+1)\times \cdot 63} \cdot \frac{2\pi \cdot 133 \cdot 10^8}{3\times 10^{10}} \cos \alpha \text{ in C.G.S. electrostatic units.}$$

$$= \frac{K}{4\pi} \cdot \frac{\sqrt{2} \cdot 8800}{(2K+1)\times \cdot 63} \cdot \frac{2\pi \cdot 133 \cdot 10^8}{(3\times 10^{10})^2 \times 10^{-1}} \cos \alpha, \text{ amperes}$$

$$= \frac{K}{2K+1} \frac{14\cdot 6}{10^7} \cos \alpha$$

$$\therefore = \frac{K}{2K+1} \frac{10\cdot 3}{10^7} \text{ amperes, effective, per unit cross section.}$$

Each of the coils for the magnetic field contained 1200 turns of No. 18 B. & S. magnet wire; H, the intensity of the magnetic field at the center of these coils, as calculated with a neglect of the influence of the ends, was 200 i, i being the current in amperes; as measured by the electromotive force induced in an exploring coil of known area and number of turns, H was 166 i, (area of exploring coil 25^{cm^2}, 400 turns; observed E.M.F., with 2·4 amps. in coil, 33·5 volts, 133 cycles). The resistance of each coil was about 9 ohms, and the calculated value of the coefficient of self-induction was L = ·109 henry; at 114 volts, 133 cycles, each took 1·3 amperes which corresponds to a value ·104 for L. If θ be the difference in phase between the E.M.F. and current, i. e., the angle of lag, we have:

$$\tan \theta = \frac{2\pi NL}{R} = \frac{6\cdot 28 \times 133 \times \cdot 104}{9} = 9\cdot 3, \text{ whence } \theta = 83^\circ\ 52'$$

Now consider the phase relations between the displacement current and the alternating magnetic field from the sketch of the connections. Since the difference in phase between the primary and secondary E.M.F's of a transformer is approximately 180°, the E.M.F. on the electrodes having passed through two transformations has returned to coincidence of phase with the generator E.M.F. and may be indicated by sin α. The resulting displacement current has the phase cos α as shown above, i. e., differs by 90° from the generator E.M.F. The E.M.F. impressed on the coils has been transformed

once, suffering retardation of 180°; owing to the self-induction of the coil the resulting current lags approximately 90°, and so, therefore, does the resulting magnetic field. Consequently, the displacement current and magnetic field are approximately 180° apart, that is, in the proper relation to give the electromagnetic reaction. Actually, since the angle of lag in the coil is 83° 52′ instead of 90°, the effect as calculated for coincidence must be multiplied by ·9942 = cos 6° 8′.

The current in the dielectric is thus acted on by a force:

$$\cdot 994\frac{lq\,\mathrm{H}}{10} = \cdot 63 \cdot \frac{\mathrm{K}}{2\mathrm{K}+1} \cdot \frac{10\cdot 3}{10^7} \cdot \frac{166\times 1\cdot 2}{10} \cdot \cdot 9942 \cdot$$

$$= \frac{\mathrm{K}}{2\mathrm{K}+1} \cdot \frac{12\cdot 8}{10^6} \text{ dynes.}$$

when 1·2 amperes flows in each coil, l being the thickness of the dielectric, or the length of the displacement current acted on by the field, and H the intensity of the magnetic field. This force is applied in opposite directions at the two ends of the suspended beam, which was 17·78^{cm} long, giving thus a couple of

$$\frac{\mathrm{K}}{2\mathrm{K}+1} \cdot \frac{2\cdot 28}{10^4} \text{ dyne-centimeters.}$$

The angle of twist of a thread of length l, radius r, coefficient of rigidity n, acted on by a couple u is:

$$\Phi = \frac{2\,lu}{\pi r^4} \cdot \frac{1}{n}.$$

The length of the quartz fiber was 101·6^{cm}; its radius was estimated by comparison under a microscope with the spaces of a grating ruled on glass, the grating space of which was known, and did not differ greatly from ·0006^{cm}. The value of n being taken at 3×10^{11} for quartz,* we have

$$\Phi = \frac{\mathrm{K}}{2\mathrm{K}+1} \cdot \frac{2\times 101\cdot 6\times 2\cdot 28}{\pi\times \cdot 0006^4\times 10^4\times 3\times 10^{11}} = \frac{\mathrm{K}}{2\mathrm{K}+1} \cdot 37 \text{ radians.}$$

Taking the value of K for rock salt as 5·8, we have $\Phi = \cdot 173$, which, since the distance from the mirror to scale was 140^{cm}, represents a deflection of $2\times 1400\times \cdot 173 = 485^{mm}$, or more, since we have taken the tangent as equal to the arc.

The calculation above assumes that the electric and magnetic fields remain constant through the range of movement of the dielectrics. It was of course foreseen that the electric field would be most intense at the center of the space between the electrodes and so would tend to hold the dielectric within that region; nevertheless it was thought that a couple of the magni-

* Threlfall and Boys.

tude above indicated would to a certain extent overcome this tendency. The test for the true effect seemed to lie in a reversal of the sense of the deflection when the phase of either the electric or the magnetic fields was changed by 180°.

Results.—When the electric field alone was applied, the beam, as was expected, found a stable zero position near the center of the electrodes. With a fiber 20^{cm} long this position could be upset by 10 to 20^{mm} on the scale, by a very small twist of the torsion head. This test was not so satisfactory when the long fiber was used, owing, apparently, to the large inertia of the suspended system, and to the arising of other disturbances within the time necessary for the torsion of the fiber to make itself felt. The zero point was always quite steady, having practically no oscillation, but was not always the same, varying within two centimeters. This indicated that near the center there was a region of fairly uniform electric field, and also that, owing to the mass and damping of the suspended system, the torsion of the fiber could not be depended on to give the zero position. The mass of the beam and dielectrics was from 2 to 3 grams, varying with the nature of the dielectric; of this the greater part was in the dielectrics. Fibers of the size here required broke if the mass were 3 grams or more.

The method of procedure was to allow the beam to come to rest under the influence of the electric field alone, the long time required for the oscillations about the central position to die out being another evidence that the field there was fairly uniform. Then the magnetic field was put on and the resulting deflection noted. Then either the electric or magnetic field was reversed, the deflection noted, and so on. The deflection was generally small and quite slow in all cases, requiring considerable time to become steady; in most of the observations only the sense of the deflection was noted. Proceeding in this way, several hundred observations were taken; they were generally negative in result, that is, the deflection did not change in either direction or amount when either field was reversed. At times, however, there were indications of the effect looked for, as is shown by the following description:

The electric field and then the magnetic field being put on, as described, with the values and conditions as given above, there resulted an uncertain deflection of about 1^{mm}, which did not reverse with a reversal of the magnetic field. The circuits were then arranged so that 200 or 400 volts might be impressed upon the coils. With 200 volts a deflection of from 5 to 10^{mm} was obtained, which, however, did not reverse with a reversal of the magnetic field; this deflection was towards a position which the beam tended to take when under the influence of the magnetic field alone. With paraffin as the dielectric the

proper reversal was obtained to the extent of 4 or 5^{mm} on two occasions, one with a reversal of the electric field, the other with a reversal of the magnetic field. In both instances the deflections were from a zero position constant within 1^{mm}, and appeared as a slow motion immediately on closing the switch. The above mentioned disturbing effect of the magnetic field was always evident through all the experiments, but in this form of the apparatus in several instances there were distinct initial deflections in opposite sense to this tendency.

When the switches remained closed long enough, the above disturbing tendency seemed to predominate regardless of the direction of the field. The question at once arose as to whether it was a magnetic or an electric effect. Experiments with bits of iron filing on the dielectrics, with hard rubber known to be slightly magnetic, with rock salt which gave no trace of magnetic impurities, and with both direct and alternating currents, indicated that a part of this disturbing influence was due to the difference in the intensity of the magnetic field at the center and close to the side of the coil. For this reason only rock salt, glass and paraffin were used, as they appeared quite free from magnetic impurities; with them the disturbance was less than with sulphur and hard rubber, though it was still the predominating influence. Further experiments with rock salt several times gave evidences of the proper reversals to the extent of 2 or 3^{mm}; and with glass on one occasion the expected reversals of deflection were noticeable for six switch reversals; these deflections were only 2 to 3^{mm}. Very long waits between readings were necessary owing to the difficulty of obtaining a steady zero; this was probably due to air currents set up within the case caused by the heating of the coils when on the 200 volt circuit; the six readings mentioned required one afternoon. On the next day the proper reversals of deflection were observed for four reversals each of magnetic and electric fields; they were from 2 to 5^{mm}.

It must be stated, however, that these proper deflections were taken from among a mass of attempts which resulted sometimes in no deflection at all and at others in deflections in the wrong sense. While it was sometimes possible to account for these by a steady shifting of the zero position, I still questioned whether I had obtained the effect, and looked to the improvement of the apparatus.

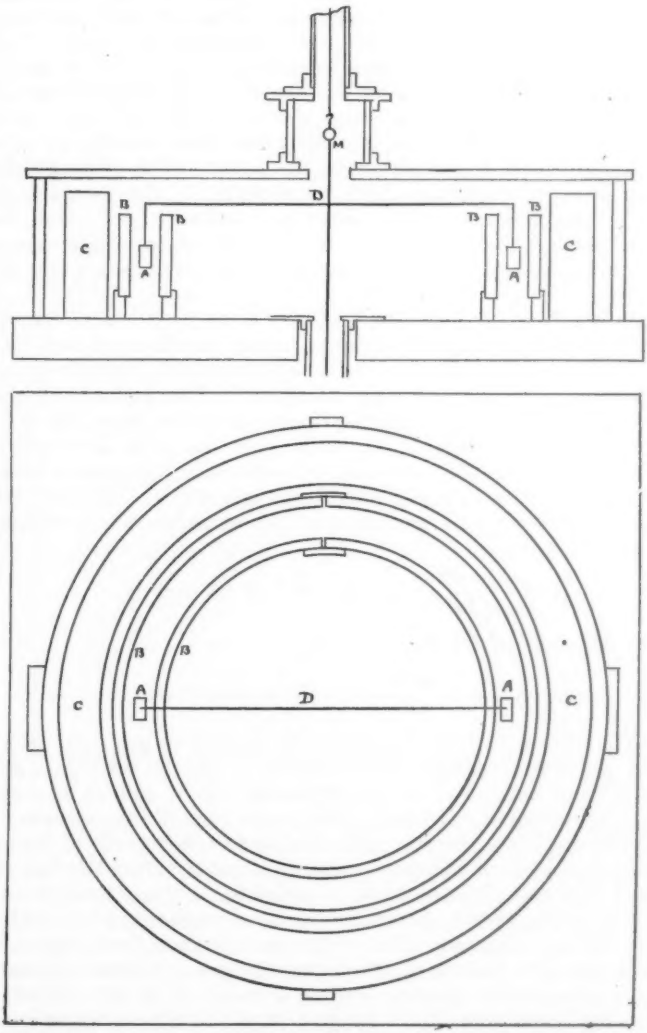
Second and Third Form of Apparatus.—In the second form the air space was reduced and the electric screening made better by enclosing only the electrodes and suspended system within the case, the coils being outside. The case was entirely of brass, the posts of the electrodes being set in insulating bushings. To prevent secondary currents in the cylindrical

cases, they were each split down an element of the cylinder; these splits were covered and were on the front of the case, i. e., diametral planes through them cut the beam, in its central position, at right angles. The conditions were not improved by the apparatus in this form; if anything, the disturbance due to the magnetic field alone was worse, and it always caused a movement of the dielectric towards the side of the casing to which it happened to be nearer. Still thinking it a magnetic effect due to the more intense field near the coils, a single large coil which would completely surround the entire case and have its center in the line of the fiber, was wound. The field due to this coil would be uniform around any circle concentric with the coil; the coil was $7{\cdot}62^{cm}$ high, had an internal diameter of $26{\cdot}6^{cm}$ and contained 360 turns of No. 15 wire. The conditions were not improved by the use of this coil, and it was still impossible to look for the true effect. This seemed to indicate that the disturbance was not magnetic, nor could it be due to electrostatic influence of the coil since the shielding was practically perfect. It was thought then that the electromotive force induced in the cylindrical metal case must set up a field in the slit down its side sufficient to cause the disturbances. To test this the slits were closed with solder, and new ones cut directly back of each of the outer electrodes; the disturbance disappeared almost entirely. Tests were then made with the single large coil and also with the two single coils; the constants for the large coil introduced no considerable difference in the calculated effect; the conditions in each of these series of tests were quite good; the electric field alone caused a good steady zero position; on closing the switch of the magnetic field there was usually no deflection at all, only a slight oscillation; sometimes there was a deflection of 1^{mm} or 2^{mm}, which, however, did not reverse on reversal of field and was probably a survival of the old disturbance.

Fourth Form of Apparatus.—As has been pointed out, the design of the electrodes in the experiments above described caused a position of stable equilibrium for the dielectrics, and it was thought that if the electric as well as the magnetic field were uniform and constant for all positions of the beam, the conditions would be greatly improved and practically as favorable as the method permits. To this end the final form of the apparatus was constructed: The large coil described above was used for the magnetic field; as shown in fig. 4, the electrodes were two complete rings of brass, set concentric with each other and with the coil. The surfaces were carefully turned and polished, and each ring was split in one place to prevent its becoming a short circuited secondary circuit. The true circular form of the ring was maintained by bridging the split

with a strip of hard rubber; the splits in the two rings were in the same diametral plane. The rings were set on small, hard

4



rubber chairs, and carefully levelled and spaced so as to be as nearly as possible the same radial distance apart at all points; this distance was 1·9^{cm} ($\frac{3}{4}''$). In the earlier experiments this

distance was varied, and 1·9^{cm} was found to be the minimum practicable separation, anything less resulting in the dielectrics receiving a charge which would draw it against the surface of one of the rings; for any distance between the electrodes this always happened in damp weather. The coil was carefully sheathed with tin-foil which was connected to earth. The suspension hook on the beam was lengthened so as to reach into a glass tube shown in the sketch at M and the mirror placed on it there. By moving the source of light and scale in a circle about the apparatus, it was thus possible to take observations in any position of the beam. The walls of the glass tube scattered the light somewhat, but the intensity of the Nernst filament was so great as to always give a well defined line on the scale. The whole deflecting apparatus was suitably enclosed so as to be free from disturbance by air drafts.

Calculation of Expected Effect.—With 8800 volts on the electrodes and with dielectrics of glass, paraffin and rock salt, the order of magnitude of the displacement current is not different from that already calculated. The angle of lag of the current in the coil, that is, the phase of the magnetic field, and also the intensity of the field, had also to be determined. The angle of lag was obtained by measuring the current taken by the coil at a known voltage and frequency. At 400 volts and 133 cycles this current was 10 amperes, the resistance being 4 ohms:

$$10 = \frac{400}{\sqrt{16 + 835\,L^2}}, \text{ whence } L = \cdot 05 \text{ henry};$$

also the angle of lag, θ, is given by

$$\tan\theta = \frac{2\pi NL}{R} = 10\cdot 45, \text{ or } \theta = 84^\circ\ 28'.$$

The intensity of the magnetic field at various positions within the coil was determined by sending a current through it and measuring the E.M.F. in an exploring coil of known area and number of turns. At 200 volts the current in the coil was 5·3 amperes. The exploring coil consisted of 400 turns of No. 33 wire, and had an effective area of about 25·8^{cm}. Moving the exploring coil along a radius by equal steps, the following readings give the curve, shown in fig. 5, of variation of the intensity of the magnetic field with the distance from the coil; ordinates are values of the intensity and abscissæ distances from the center, the coil having a radius of 13·6^{cm}. The deflecting beam was 22·2^{cm} long, so that the dielectrics swing at a radius of 11·1^{cm}, and at this distance the field, with 5·3 amperes in the coil, had an intensity of approximately 220, or 42

per ampere, thus of the same order of magnitude as in the calculation for the first form of the apparatus. The suspension fiber was also the same, and so, therefore, the order of magnitude of the calculated deflection.

Position	Volts
Center	7·8
1	8·1
2	8·6
3	9·9
4 (near coil)	12·1

Results.—With this apparatus, when the electric field alone was put on, the beam after a sufficient time always found a

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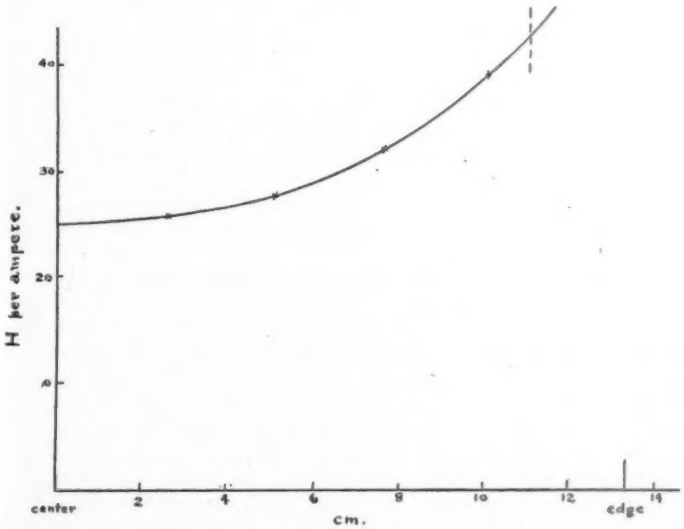


position of equilibrium, in some places stable and at others unstable. The former seemed to be in a diameter which passed through the hard rubber supporting chairs of the rings, doubtless owing to a slight concentration into the chairs of the field of force; a slight departure from this line was sufficient to cause the beam to wander to some other position, and the indications seemed to certify a quite uniform electric field. On putting on the electric and then the magnetic fields, (5·3 amperes in coil) there was a deflection of from 2^{cm} to 3^{cm}, which, however, did not reverse or show any regular difference in amount when either field was reversed; it was found that the magnetic

field when on alone gave a deflection in the same direction. Thus the magnetic field when on alone also had an effect on the position of the beam. With the beam at rest, when this field was made a slow drift away was generally seen, the beam coming to rest in some other position. Repeated efforts failed to locate single positions that it seemed to prefer, though in certain neighborhoods the direction of the deflection seemed the same. In some positions there was no deflection, though these were never the zero positions for the electric field alone; the problem then seemed to bring the two zero positions together.

Since the disturbance due to the magnetic field did not appear to be the influence of the splits in the ring as before, for it seemed independent of the distance of the dielectrics from them, and since the intensity of the magnetic field was uniform, it therefore seemed that direct electric influence of the coil or leading-in wires must be the cause, though the tin-foil screen seemed as perfect as possible. The attempt was then made to bring one of the positions in which the beam seemed unaffected by the magnetic field alone, into coincidence with a zero position for the electric field alone, by turning the coil into various positions about its center. This process was most tedious, involving as it did long waits for the beam to come to rest, and at its best it seemed only a hit-or-miss method. The condition sought, however, seemed so desirable, that repeated efforts were made to bring it about. One of them succeeded; and while the result obtained must be discredited in view of the failure of all attempts to repeat the proper conditions, and of other negative attempts, it is nevertheless thought that the following quotation from a note taken at the time should be inserted here: "this condition was obtained March 18th; the beam was allowed to come to rest under the electric field; this was then cut off and 400 volts put on the magnetic coil, which caused no deflection of the beam. On putting on both fields there was a slow deflection to the right of between 1^{cm} and 2^{cm}, about one minute being required. The magnetic field was then taken off and the beam allowed to move under the electric field alone; it resumed the former zero after one or two minutes. The magnetic field was then put on reversed; there resulted a much stronger deflection to the left which was allowed to continue several minutes, resulting in a deflection of 5^{cm}. Repetition could not be obtained, due to the fact that after the large deflection the beam did not return to the original zero position. (The heating of the apparatus due to the large current in the coil (10 amperes) when applied for any length of time frequently upset the equilibrium positions.) The conditions, however, of the above observations were so favorable that my belief in the presence of the effect was

much strengthened after the many recent failures to detect any evidence of it."

Failing to repeat the condition as above described, a light strip of wood was placed along a diameter on top of the inner ring. This strip took up a sufficient charge to give the beam the position of delicate equilibrium when the beam was parallel to it, i. e., directly over it; it could be rotated to any position on the ring without opening the case, by means of a device not shown in the sketch; the rod of the damping vane passed through a hole at its center. A number of experiments were made with the following order; the beam was allowed to find a stationary position under the influence of the magnetic field alone. The interior being visible through the glass cover of the casing, the wooden strip was turned so as to be parallel to and directly under the beam, with the idea that the zero positions for the two fields would be brought into coincidence. It was found that in most cases any movement of the strip would upset the position of equilibrium due to the magnetic field. Frequently, however, the condition of coincidence was approached, and in all these instances when the effect was looked for the results were either spurious or negative. That is, if there was a deflection, as sometimes to the amount of 1^{mm} or 2^{mm}, neither its direction or amount changed with a reversal of field; or often there was no deflection at all for either phase of the field.

Differences in deflection for the two phases of either field were now looked for; the wooden strip was discarded and the beam allowed to find a stationary position under the action of both fields. That is, the electric field was put on and a steady state reached; then the magnetic field, resulting in a deflection of usually between one and two centimeters to a new position of equilibrium. The magnetic field was then quickly reversed and a change in the position of the beam looked for. In a series of observations in which the conditions seemed perfect, no change at all could be noted when the field was reversed, there being either no deflection at all, or less than 1^{mm} without regularity. In these experiments the coil only carried 2·6 amperes, giving a calculated effect one-half of that estimated above; 5·3 amperes, i. e., 200 volts on the coil, during the time required for the beam to come to rest, heated the interior to an extent sufficient, by reason of air currents or expansion of the ring electrodes, to cause erratic oscillations of the beam about its zero position.

While it was thought that at the comparatively low frequency of the alternating circuit, 133 cycles per second, a possible lag of the displacement current, owing to molecular friction or other cause, could hardly make itself felt, it nevertheless seemed

worth while to shift the phase of either the electric or the magnetic field by a quarter of a period. For this purpose a two-phase machine was used, one phase being put on the primary of the high tension transformer, the other directly on the magnetizing coil. This separates the displacement current and magnetic field by one-quarter of a period, if there is a lag of one-quarter of a period in the coil due to its self-induction, as was approximately the case in the experiments already described. The machine operated at 38 cycles, and 85 volts per phase; the resulting displacement current is thus

$$\frac{38}{133}\times\frac{85}{110}=\cdot 23$$

of the value calculated for the first arrangement; at the lower frequency and voltage, however, the coil took 6·2 amperes, so that the magnetic field is $\frac{6\cdot 2}{5\cdot 3}=1\cdot 17$ times that in the first arrangement, so that the calculated magnitude of deflection is still appreciable; the angle of lag is given by

$$\tan\theta=\frac{2\pi NL}{R}=\frac{237\times\cdot 05}{3\cdot 9}=3\cdot 05,\ \therefore\ \theta=72^\circ.$$

The circuits were also arranged so that both electric and magnetic fields might be put on the same phase or one on each; this permitted, with the use of the reversing switches, a rapid change of phase of either approximately 90° or 180° between the displacement current and the magnetic field. In a series of observations with this arrangement there appeared to be no difference among the results of the several combinations of phase. The beam was allowed to come to rest under the electric field alone; on putting on the magnetic field there was the usual deflection, but there was no evidence of any change either in direction or amount of this deflection when the phase relations were altered at random.

Summary and Conclusions.

The mass of the evidence of this research is against the presence of the magnetic effect of electric displacement in an amount given by Maxwell's expression. The single positive result obtained with the final form of the apparatus must be questioned, for although the favorable conditions under which that result was observed could not be obtained a second time, it is thought that at times they were approached sufficiently to give traces of any effect as great as that noticed. The final form of the apparatus was undoubtedly that most likely to give results; in it there appear to be only two influences which might pre-

vent the effect sought. The first is a variation in the intensity of the electric field from point to point and the tendency of the dielectric to remain in the region of greatest intensity; and the second, the presence of the damping vane. It is thought that neither influence was great enough to mask a couple of the value of that sought; as has been stated, the rings were carefully turned and adjusted in place so that their surfaces were the same distance apart at all points. Indications of any choice of position by the beam in the electric field were of the slightest, the stationary positions being very easily upset, and often changing by one or two centimeters between readings. The distribution of the electric field due to the coil, though uncertain, could not have departed greatly from symmetry about the center, and since the disturbance due to it manifested itself in deflections rarely exceeding 1^{cm}, it does not seem possible that the variations of intensity were great enough to account for the absence of visible effect when the displacement couple acting on the beam was reversed. In the earlier experiments several series of observations were made without the damping vane; no difference in the behavior or in the nature of the results was observed except the increase in time necessary for the beam to become stationary. Observations could not be made with the final form of the apparatus if the damper were taken off; the electric field was so nearly uniform that the beam would not retain a stationary position definite enough to be taken as a zero point.

The following arrangement, independently conceived, but afterwards discovered to be an improved modification of the apparatus used by S. P. Thompson, offers a possible means of detecting a magnetic effect of the displacement current. An Annulus $1{\cdot}9^{cm}$ thick, built up in laminations of sheet iron rings $3{\cdot}18^{cm}$ inside and $7{\cdot}6^{cm}$ outside diameter, was wound with a coil of several hundred turns of fine wire, which was connected with a telephone receiver. In the opening in this magnetic circuit was placed a cylinder of dielectric $2{\cdot}54^{cm}$ in diameter and $2{\cdot}54^{cm}$ in length. Flat electrodes were brought very close to the ends of the cylinder, but were not allowed to touch it. When now an alternating E.M.F. is applied to the electrodes the resulting displacement current should set up an alternating field in the surrounding magnetic circuit, and so induce a current in the telephone receiver. The space between the electrode and dielectric prevents in great measure a possible conduction current due to conductivity of the material of the dielectric. With 8800 volts at 133 cycles on the electrodes, neglecting the air gaps, and with paraffin ($K=2$) as the dielectric, the displacement current density is:

$$q = \frac{2}{4\pi} \cdot \frac{\sqrt{2} \,.\, 8800}{2 \,.\, 45} \cdot \frac{2\pi \,.\, 133 \,.\, 10^8}{(3 \times 10^{10})^2 10^{-1}} \cdot \frac{1}{\sqrt{2}}$$

and the total amount is

$$6{\cdot}45\ q = 3{\cdot}34 \times 10^{-6} \text{ amperes.}$$

The experiment was tried with paraffin and with hard rubber and no sound could be detected in either case. The question whether the telephone receiver would respond to such a small current was of course still open, nor could it be completely answered. The following approximation was, however, made: a conductor was placed through the opening of the iron annulus and included in a circuit with an ammeter, a resistance, and a source of alternating electromotive force in low values; the lowest division on the ammeter scale was ·02 amperes, and the voltage was adjusted to give this reading, the telephone receiver giving a good note. Resistance was then inserted by steps up to about 100 ohms (inductive), apparently bringing the ammeter needle to zero; sound in the telephone receiver was still audible, though faint. The experiment was performed very roughly and hurriedly, and is susceptible of considerable improvement.

The writer's thanks are extended to Professor Ames for his interest and kindness in furnishing every facility needed in the course of the investigation.

The mechanical work was done by Mr. Charles Childs; for his skill and interest at all times the writer wishes to extend his appreciation.

It is proposed to carry this work further in both forms of apparatus.

Physical Laboratory,
Johns Hopkins University,
May, 1902.

Art. XVI.—*Certain Relations of Plant Growth to Ionization of the Soil;* by Amon B. Plowman.

In a series of experiments now in progress at the Harvard Botanic Garden, there have been observed some interesting phenomena in the relations of plants to electricity. The experiments have been of a widely varied nature, dealing with both static and kinetic charges, through a range of potential from 0·5 to 500 volts. Either platinum or high-grade carbon —usually the latter—was used for electrodes, and special care was taken to insure normal conditions of temperature, light, and moisture.

The experiments were of course checked off by controls, always using at least two different sets of controls in order to avoid accidental errors. In a well-lighted greenhouse it is not a difficult matter to locate the different plants in such a way as to give fairly uniform light to all. For soil-cultures, pots of the same size were used, filled with equal amounts of carefully prepared soil, and supplied with measured quantities of water.

The regulation of temperature presented serious difficulties whenever a considerable amount of current was used, for the resistance of the soil is very great and much heat is evolved in forcing the current through it. Thus a 500 volt circuit, joined through a body of soil 10×25^{cm} in cross-section and 40^{cm} long between electrodes, gave a current of 0·2 ampere, and in one hour raised the temperature of the soil from 16° to 44°C.

However, with a slight excess of moisture and a current not exceeding ·05 ampere, it has been possible to prevent a rise of temperature of more than 3° above the normal; and in most cases the temperature has been kept within a range of 1° above that of the control. In the matter of temperature-regulation the water-culture method possesses many advantages. Either by a slow circulation of the electrolyte, or by a more rapid circulation of water about the vessel containing the electrolyte, it is easy to maintain a constant temperature even when using currents of 2 amperes. In this way it is possible to introduce a very considerable electrical factor without seriously disturbing the other relations of the plants.

Among other facts recorded in the course of these experiments is the following: Seeds placed near the anode are always killed by current amounting to ·003 ampere or more, if continued for twenty hours or longer, while seeds placed near the cathode have in most cases been but little affected, and under some conditions have been apparently stimulated by such currents.

When the seeds were germinated in water this difference was most pronounced when a relatively heavy current was passed through the water for only a short time, in which case the seeds near the anode were killed, while those near the cathode were not apparently injured. If the current was allowed to flow for twenty hours or longer the ill effects were produced at all points between the electrodes, even when the current amounted to only ·003 ampere, at a voltage of 2 or more. When the current was passed through ordinary sandy soil in which the seeds were planted, the same results were obtained at the anode, but a much longer time was required to extend the injurious effects to the region of the cathode. Indeed, so long as the current does not exceed about ·08 amp. there is a considerable increase in the rate of growth of the seedlings near the cathode.

In explanation of these phenomena the following provisional theory is offered.

Whenever two points in any electrolyte are electrically charged to different potentials, the movement of the free ions in the solution* is given definite direction, and, if the difference of potential is sufficient, further dissociation of the electrolyte follows. The anions with their negative electrons move toward the anode, and the cations with their positive charges pass to the cathode. Since the movements of ions in solutions are relatively slow,† it is reasonable to suppose that in the region of the anodes there would be a slight excess of positive ions, due to the rapid neutralization of the negative ions by the positively charged electrode. In like manner the cathode removes the positive ions in its immediate vicinity, and is consequently surrounded by a slight excess of negative ions. The more slowly the ions move through the electrolyte the more marked will be the difference of conditions about the two electrodes.

How will seedlings respond to these differences of conditions? It is clearly indicated by the results of our experiments that vegetable protoplasm is paralyzed and quickly killed by the conditions existing about the anode, while within certain fairly broad limits it is stimulated by the conditions about the cathode. While the dissociation of the atoms and electrical separation of the ions must bring about slight differences of a purely chemical nature in the region of the electrodes, yet

* Ostwald and Nernst. Ztschr. phys. Chem. iii, 120, 1889.

† Kohlrausch (Wied. Ann. l. 403, 1893) has shown that, in an electrolyte of unit potential gradient, the velocity in centimeters per second for certain ions is as follows :—

Cations				Anions.			
H	·00320	NH_3	·00066	OH	·00182	I	·00069
Na	·00045	Ag	·00057	Cl	·00069	Ni	·00064
Li	·00036	K	·00066				

these mere chemical differences can hardly account for the effects upon the plants, even *near* the electrodes, and certainly not for certain effects at points mid-way between the electrodes. This conclusion is borne out by the following facts :—

1. When seeds are germinated in distilled water through which a weak current is forced, the O ions are in excess in that part of the solution where stimulation occurs, and the H ions are in excess where the plants are killed. But it may be shown that small quantities of hydrogen are not markedly harmful to plants. And the quantity of oxygen set free in distilled water by a weak electric current is certainly no greater than that normally present in ordinary tap-water, such as was used for the controls; yet germination is often more rapid near the cathode than in the case of the control.

Apparently, the effects are produced by the *electrical charges* of the ions, rather than by any mere chemical activity of the atoms.

2. When seeds are placed in solutions of various acids, bases, or salts, of a degree of concentration far below the " killing point," they will germinate quite as well as in ordinary distilled water. But when a current of electricity of sufficient strength to propel the ions is passed through the solution, that part about the anode becomes destructive to plant life.

From these and other facts we conclude that *negative charges stimulate*, and *positive charges paralyze*, the embryonic protoplasm of these plants. This is strikingly in accord with the conclusions reached by Matthews* in his experiments on the nature of nerve stimulation, in which he shows that the sciatic nerve of the frog is stimulated by negative ions, and rendered less irritable by positive ions.

In support of the theory here advanced the following facts may be mentioned :—

1. When a flower-pot containing several lupines of about four weeks growth is charged to relatively high potential (500v.) with positive electricity, the plants cease to grow, gradually lose their turgidity and finally die. On the other hand, when a *negative* charge is used these effects are *not* produced, but the plants are actually stimulated.

It is evident that, in the first case, the negative ions in the soil are drawn to the positive terminal, while the positive ions are driven to the plant. In the second case, the positive ions are drawn to the negative electrode, and negative ions are driven to the plants.

2. When seedlings are grown in an aqueous culture-medium through which a weak current of electricity is flowing, the

* Science, vol. xv, No. 378, 1902.

root-tips turn toward the anode. An attempt has been made to show an analogy between this movement and a similar turning of root-tips "up stream" against a water current. However, the analogy is of little value, owing to the fact that in the electrolyte there is a streaming of ions in *both* directions. Hence, the question is not so much a matter of the direction of the electric current as it is of the difference in effects of the two streams of ions.

Upon examination of the conditions which prevail about roots growing in an active electrolyte, we find that the side of the root toward the anode is being bombarded by a stream of *positive* ions moving toward the negative electrode, while the side toward the cathode is exposed to the stream of *negative* ions on their way to the anode. Consequently the side of the root toward the cathode is stimulated, and that toward the anode is retarded, in its growth, and of necessity the root-tip curves toward the anode.

Seedlings grown in ordinary soil show this curvature even more strikingly. The main axis of the plant is frequently curved almost 90° just below the surface of the soil. The curvature is toward the anode and away from the cathode, whether these be in circuit or isolated.

3. Normally, the plant body is electro-positive to the soil in which it grows. The potential difference appears to be a function of the physiological activity of the plant. The positive charge of the plant attracts the negative ions of the soil to its roots. Thus it seems that negative electrons are being constantly discharged to the plant as a natural condition of its life-activity. Any circumstance which would facilitate this electrical interchange we should naturally expect to be beneficial to the plant, while the reverse condition would be detrimental.

It must be borne in mind that the phenomena with which we have been dealing are conditioned not only by temperature, light, aeration and moisture, but also by the nature of the electric current used, the solution-tension of the electrodes, the osmotic pressure of the electrolyte, the degree of dissociation of the electrolyte, the valence of the ions, the physical state of the ions, the chemical relations of the ions to metabolic processes in the plant, besides certain peculiarities of the living protoplasm with which we are working, and which should doubtless be taken into account in connection with each of the conditions named above.

Evidently, any theory which may be advanced in explanation of the various phenomena of plant-growth in the electrical field, must stand the most exacting tests of physical chemistry, in order to be worthy of serious consideration,

Harvard University.

ART. XVII.—*Demagnetizing Effects of Electromagnetically Compensated Alternating Currents;* by ZENO E. CROOK.

THE effect on the hysteresis cycle of passing an alternating current longitudinally through an iron wire, was given in a paper published in 1891, by Dr. G. Fienzi and Professor G. Gerosia.* At a later date, Ignas Klemenicic published a paper on the relation of circular to longitudinal magnetism in iron and steel wires. He made a very brief mention of the effect due to alternating current. In the first named paper the writers found a very evident reduction of the area of the hysteresis cycle, and that a current of three amperes per sq. mm. was sufficient to totally destroy the hysteresis. When in this condition, the ascending and descending magnetization curves coincide and the effect of the magnetizing force approaches the theoretical condition expressed by Fröhlich's formula

$$I = \frac{\alpha H}{1 + \beta H}$$

in which α and β are constants for a given specimen of iron, and $\frac{\alpha}{\beta}$ is the saturation value of I. The writers thought the effect observed was due only to the demagnetizing power of the rapidly oscillating circular magnetic field. Their reason for this was that there was no perceptible jarring or vibration in the iron.

An attempt will be made in this paper to go still further into the study of the effects of alternating current on the magnetic properties of iron and steel. The main object of the study will be to discover *if there is an effect due to the current independent of that produced by the circular magnetism.*

The first question to be solved was how to eliminate the electromagnetic action, so that the effect of the current alone could be studied. This was done, approximately, by making use of the principle discovered by Ampère, that when two adjacent currents in parallel conductors flow in opposite directions, the external field of force of the one tends to destroy that of the other. In order to be effective in destroying the internal as well as the external magnetic actions of the current, it was necessary to build up the iron from very thin laminæ, and send the current in opposite directions in each alternate layer.

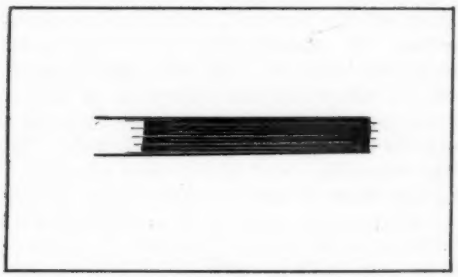
*Rendiconti de Instituto Lombardo, vol. xxiv, fasc. x, April, 1891; Electrician, April 3, 1891; Ewing, Magnetic Induction in Iron and Other Metals, page 319; Wiedemann's Annalen, vol. lvi, page 530.

Two methods of studying the hysteresis were adopted, so that the results of the one might be a check on those of the other.

First Method.

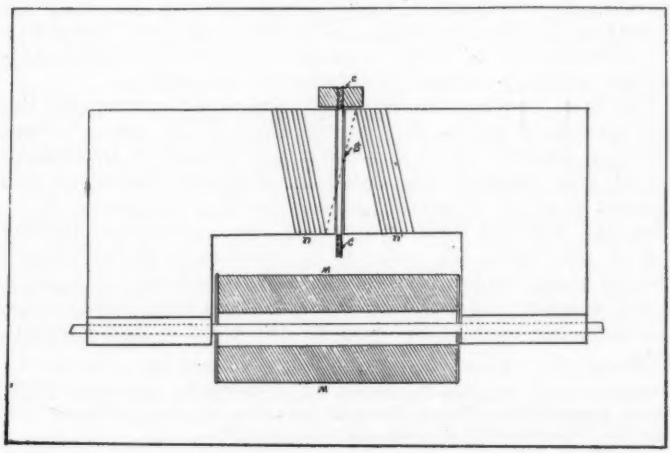
The first method was a modification of the apparatus used in the Hopkinson's bar and yoke method. The bar of iron, fig. 1,

Fig. 1.



was made up of eighteen strips of sheet iron, each 40^{cm} long, 1·9^{cm} wide and ·045^{cm} thick. These were joined at the ends, and insulated from each other by strips of shellacked paper so that a current would flow through each successive strip in the opposite direction. Allowing a small amount for the effect due to insulation between the iron strips, it was estimated that the internal magnetic action of a current flowing through the iron in the manner described above, was approximately one-

Fig. 2.

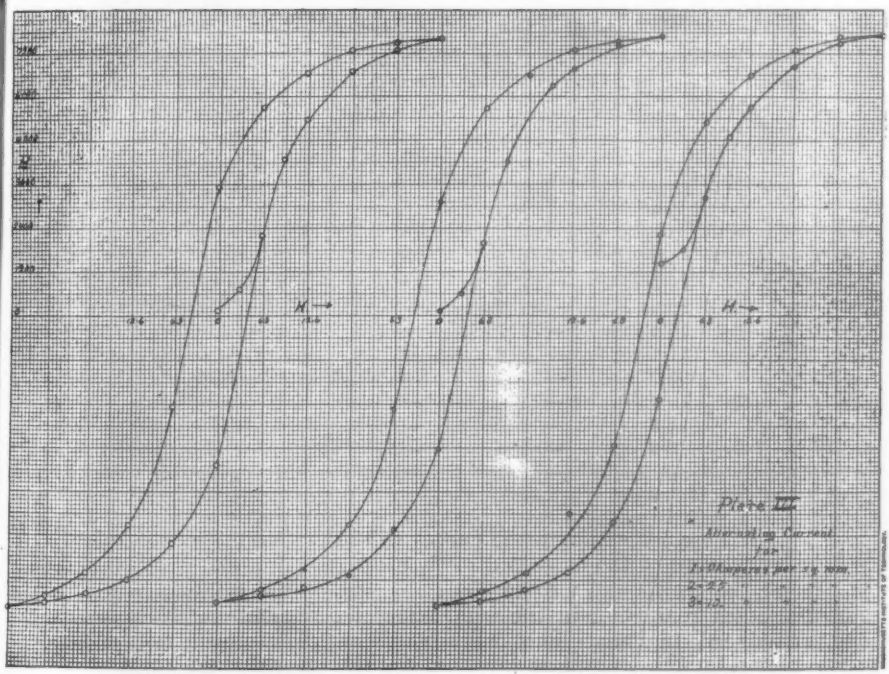


eighth of that due to a current of the same current density flowing directly through the iron strips in multiple.

The yoke, fig. 2, used was one designed by Prof. D. B. Brace and already described.*

The advantage of this apparatus over the old form of yoke is that at all times during the hysteresis test the total induction can be measured without changing the susceptibility of the magnetic circuit, and the only change in the induction is that caused by a change of current in the magnetizing solenoid.

Diagram I.



The alternating current used for demagnetization was obtained from a 50-volt circuit, transformed from a 1000 volt, 40 h. p. Westinghouse dynamo. The frequency of the alternating current was 133 periods per second.

The three hysteresis cycles given on Diagram I were all taken the same evening and under practically the same conditions.

* This Journal, vol. xi, p. 365, May, 1901.

The curves were taken in the order in which they occur on the plate and were plotted from the readings given in Table I.

Curve 1 is the normal hysteresis cycle.

Curve 2 is a cycle taken with an alternating current density in the iron to 10 amperes per sq. mm.

TABLE I.

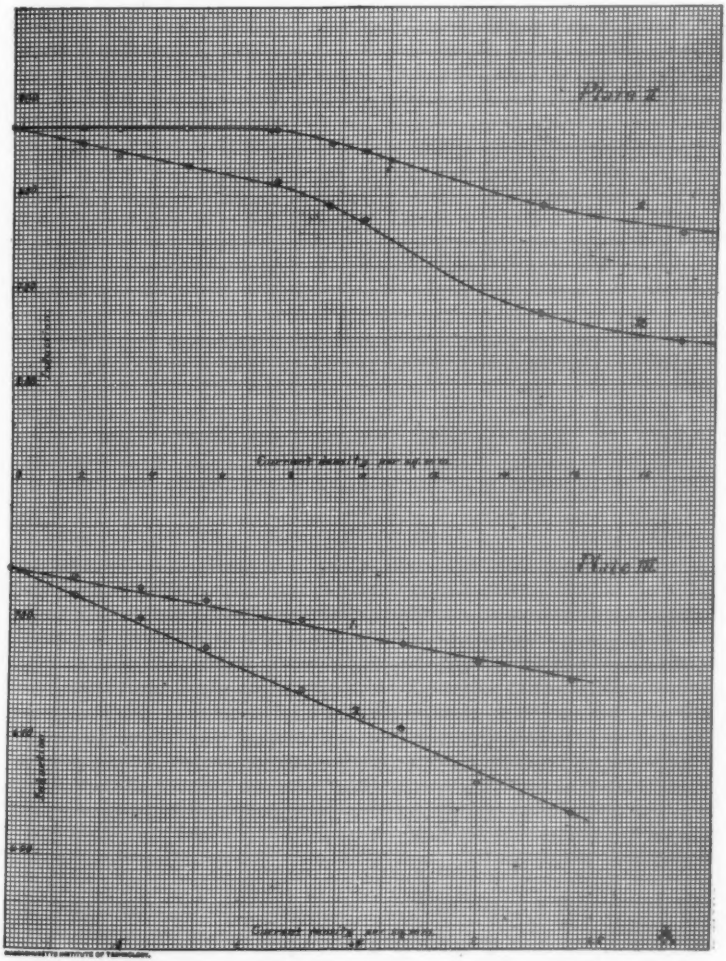
H.	B. Cycle 1.	Cycle 2.	Cycle 3.
0	174	120	1443
3·15	846	600	1815
6·3	2447	2010	3252
9·45	4329	4245	4890
12·6	5400	5415	5706
15·75		6279	
18·9	6765	6750	6939
25·2	7500	7440	7703
31·5	7590	7686	7740
25·2	7594	7604	7689
18·9	7311	7275	7320
12·6	6675	6630	6600
6·3	5730	5655	5331
0	3285	3128	2232
6·3	−2418	−2550	−3525
12·6	−5750	−5750	−6600
18·9	−6999	−6747	−7011
25·2	−7677	−7446	−7560
31·5	−7983	−7800	−7920
25·2	−7794	−7650	−7776
18·9	−7560	−7360	−7440
12·6	−7215	−6086	−6981
6·3	−6204	−5765	−5607
0	−4050	−3666	−2265
6·3	1863	2100	3249

A close inspection of the curves will show that the reduction of the area of the cycle is directly proportional to the reduction of the width and also to the reduction of the residual magnetism remaining in the iron when the magnetizing force is reduced to zero. This being the case, the problem can be considerably simplified by studying the effects of the alternating current on the residual magnetism from a constant magnetizing force, assuming that the effect on the hysteresis cycle is directly proportional to this effect on the residual magnetism.

The curves in Diagram II were taken to show the effect on the residual magnetism of varying current density in the iron strips in series. They were plotted from the readings given in Table II. Ordinates represent total induction and abscissae

represent current density per sq. mm. Curve 1 shows the effect due to a constant current; curve 2, that due to an alternating current.

Diagrams II and III.



Curve 1 (Diagram III) shows the reduction of the residual magnetism due to an alternating current of varying density passing through the iron strips in series.

TABLE II.

Current density per sq. mm.	Total residual induction. For curve 1.	For curve 2.
0	745	745
2	740	712
3	743	684
5	743	665
7·5	740	630
9	710	580
10	695	550
15	580	360
19·2	520	290

Curve 2 (Diagram III) shows the corresponding effect due to an alternating current passing through the iron strips in multiple.

Readings for these curves are found in Table III.

TABLE III.

Current density per sq. mm.	Total residual induction. For curve 1.	For curve 2.
·0	722	722
·28	719	710
·56	714	701
·84	708	689
1·25	700	670
1·68	690	654
2·2	682	631
2·5	675	618

Second Method.

The second method of studying the alternating current effect on hysteresis was carried out in the same way as the first, the only difference being in the apparatus used.

Instead of a number of narrow strips of iron connected in series, the iron specimen was made from two thin sheets of iron, separated by shellacked paper and rolled into a compact tube. The iron sheets were each 56^{cm} long, 50^{cm} wide and ·018^{cm} thick. Along the edges of the plates corresponding to the upper end of the tube were soldered "leading-in" conductors, short distances apart. This was to insure a uniform current density in all parts of the plate. The edges of the plates at the other end of the tube were bared and soldered together, so that a current entering the upper edge of one plate would flow down, across the soldered junction, back on the other plate and out by the leading-in conductors soldered to its edge.

The tube was 50^{cm} long and had an inside diameter of 2·5^{cm}. Inside of the tube was a core of wood with a copper wire running along its cylindrical axis. This system is practically equivalent to sixteen concentric iron tubes ·018^{cm} thick, with their ends so connected that a current of equal current density flows through each alternate one in the opposite direction or through all of them in multiple, according as the experimenter desires. The magnetizing coil was of the same length as the iron cylinder and wound with 300 turns No. 16 copper wire. The test coil used for measuring the magnetic flux was wound on a wooden spool made to slip over the magnetizing coil and sufficiently large and heavy to fall freely and uniformly when liberated. The cylinder was mounted inside the magnetizing coil in a vertical position, about five feet from the floor, and so arranged that the test coil would fall from the center of the cylinder to about two feet from its lower end. In this way it was possible to measure the total magnetic flux in the iron. The other apparatus was the same as that used in the first method.

It was found that the amount of residual magnetism remaining in the cylinder after applying a strong magnetizing force, was very small, and all attempts to show the demagnetizing effects on the hysteresis cycle were unsatisfactory. However, the reduction of the residual magnetism by the alternating current was quite satisfactorily shown and the results are as given below.

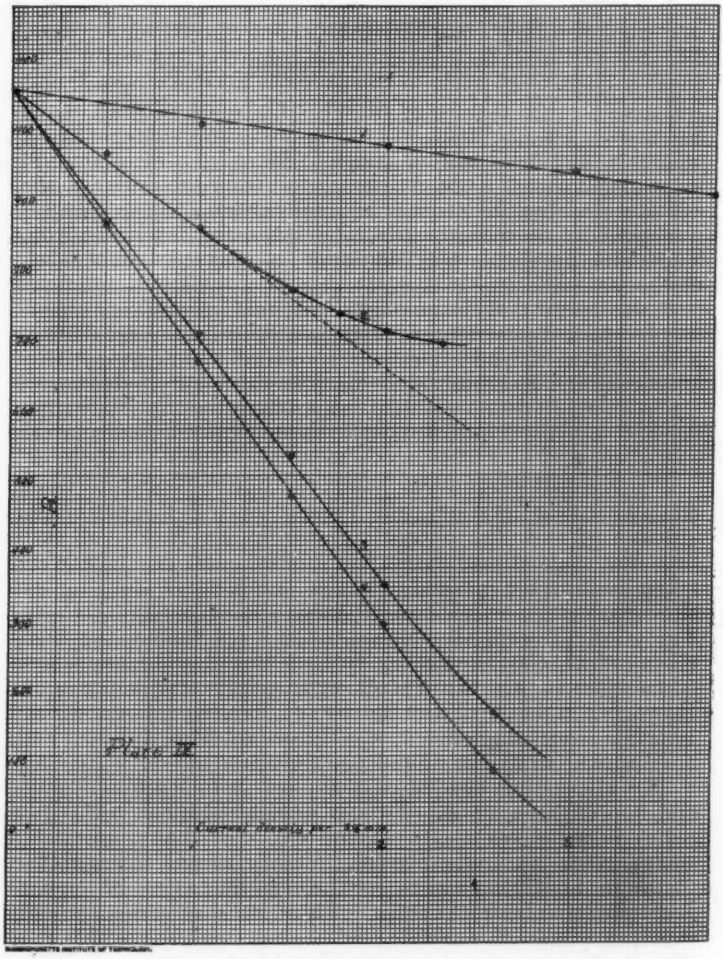
The residual magnetism left in the iron was stronger when an alternating current was present during magnetization. Because of this, the alternating current was thrown off each time the magnetizing force was applied, and readings were taken to find the residual induction before again applying the alternating current. These all gave almost constant results. The readings were all reduced to the mean value. Readings taken while the alternating current was flowing and those taken after it was thrown off were nearly always the same. However, in curve 2 the values of the residual magnetism after the alternating current was thrown off were different and are represented by the dotted portion of the curve.

The alternating current was applied in four different ways and the effects studied. First, it was passed through the iron plates in series, so as to get the effect of the magnetically compensated current. Second, it was passed through the plates in multiple so as to get the combined effect of the current and circular magnetism. Third, it was passed through the iron plates in multiple and back through the copper rod. Fourth, it was passed directly through the copper rod. The

curves, plotted from the values given in Table IV, are given on Diagram IV and are numbered to correspond to the order in which they are here mentioned.

Ordinates represent total induction, and abscissae, current densities per sq. mm.

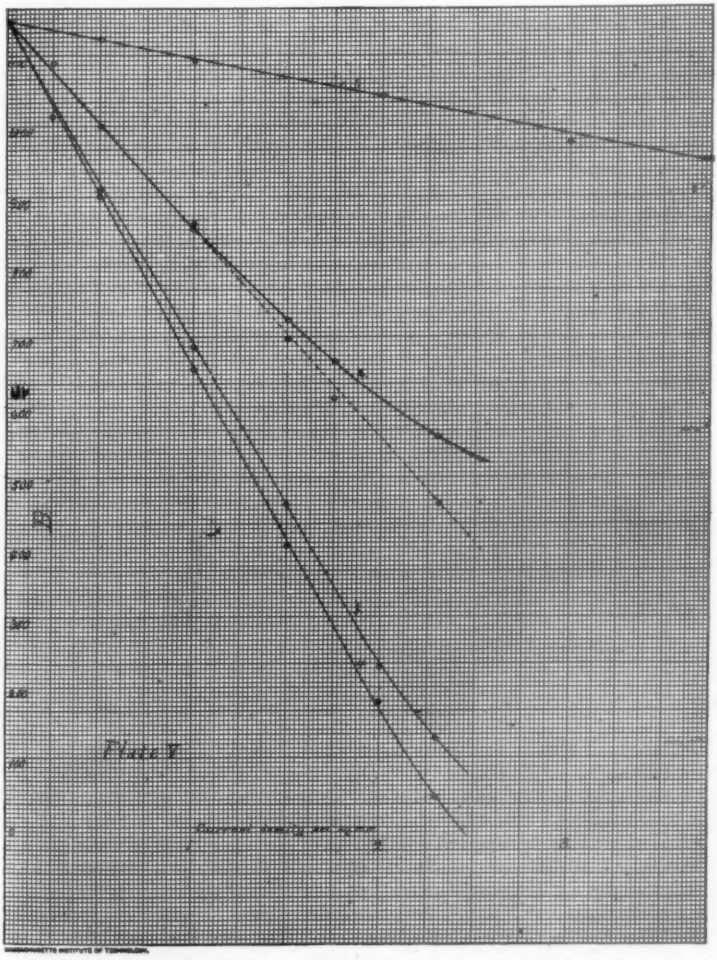
Diagram IV.



Curves similar to those given on Diagram IV were taken with the frequency of the alternating current reduced one half. They are given in Table V, and plotted on Diagram V.

The effect due to a direct current of varying current density is shown in Diagram VI. The direct current was applied by suddenly closing the circuit through the iron. A slow building up of the current had no effect on the residual magnetism.

Diagram V.



This shows that the effect was due to the sudden impulse of the current through the copper rod or through the iron. Readings for these curves are given in Table 6.

TABLE IV.

Current density per sq. mm.	Iron in multiple.	Iron and rod in series.	Rod alone.	Iron in series.
0·	1051	1051	1045	1055
·5	962	863	861	----
1·	856	660	702	1003
1·5	760	492	533	----
1·75	728	286	340	----
2·	705	----	----	970
2·29	681	----	----	----
2·6	----	80	163	----
3·	----	----	----	935
4·	----	----	----	903
4·58	----	----	----	870

TABLE V.

Current density in iron.	Total residual induction. Iron in multiple.	Iron and rod in series.	Rod alone.	Iron in series.
·0	1150	1146	1150	1150
·25	1090	----	----	----
·5	1004	1012	1010	1125
1·	865 and 855	900	908	1095
1·5	725 and 695	----	----	----
2·75	665 and 610	----	----	----
2·	--- ---	658	686	1045
2·31	560 and 465	----	----	----
3·	--- ---	400	460	975
3·5	--- ---	----	----	945
4·	--- ---	179	230	----
4·62	--- ---	45	132	870

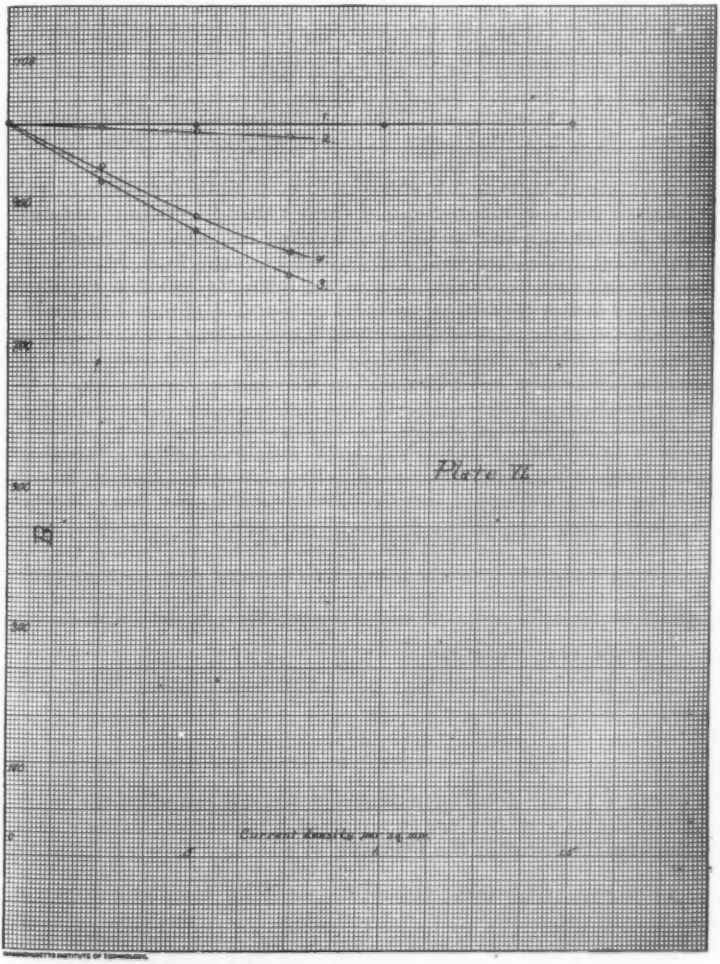
TABLE VI.

Current density in iron.	Total residual induction. Iron in multiple.	Iron and rod in series.	Rod alone.	Iron in series.
0·	1000	1001	1000	1004
·25	996	----	----	----
·5	990	940	920	1000
·75	980	----	----	----
1·	----	875	850	1003
1·5	----	820	792	1003

The hysteresis cycles given on Diagram I shows that the alternating current as magnetically compensated has an effect on the magnetic induction in iron.

The curves on Diagram II show that for low current densities, the reduction of the residual magnetism in iron, or the reduction of the area of the hysteresis cycle, is proportioned to

Diagram VI.



the strength of the current. Above 7·5 amperes per sq. mm. this relation does not hold, but heating effects and the effect

of the residual magnetism in the yoke come in to affect the induction measurements. If the values of curve 1 are subtracted from those of curve 2, the result is nearly a continuation of the straight line which gives the effect at low current densities.

The similar curves on Diagrams IV and V taken by the second method, and at different frequencies, show that the effects of the alternating current on the residual magnetism in iron are different for different frequencies, that for the lower frequency being the greater.

Curves 3, Diagrams IV and V, show that the total reducing effect of the current is approximately proportional to the strength of the current.

Curve 3, Diagrams IV and V, show the reducing effect of the external circular magnetic field from a current flowing through the central copper rod. Curve 4 shows the effect of passing a current down the central rod and back on the iron.

The force at a point in a metal tube due to a longitudinal current in the tube is expressed by the formula

$$F = \frac{2\pi w}{r}(r^2 - r_1^2)$$

in which F is the force, w the current density per unit area of the cross section, r the distance of the point from the axis of the tube, and r_1 the inside diameter. From this it is seen that at the inner surface of the tube, where $r = r_1$, the force is zero, while at the outer surface, where $r = r_2$, the force is $\frac{2i}{r_2}$. The average force in the tube due to a current flowing longitudinally along it is proportional to $\frac{i}{r_3}$ where r_3 is the mean radius of all points in the tube.

The magnetic force at a point outside a linear conductor is expressed by

$$F = \frac{2i}{r}$$

where i is the total current and r is the distance of the point from the axis of the conductor. It is, therefore, evident that the average force in the iron due to a current flowing along its cylindrical axis is proportional to $\frac{2i}{r_3}$. The magnetic force in the iron when the system was connected for taking curves 4, Diagrams IV and V, was therefore one-half what it was when it was connected for curve 3, and if the reduction of the residual magnetism was due to the circular magnetic flux alone, we

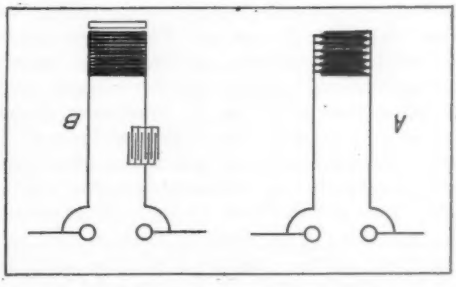
should expect the values of any point on curve 4 to be one-half that of a similar point on curve 3. Any added effect caused by the presence of the electric flow in the iron would tend to make curve 3 approach curve 4, and in fact it is found that the latter falls below the former.

If the apparatus used in the second method was as effectual in reducing the circular magnetic effects as was expected, curve 1, Diagram IV, can be taken as giving an approximate measure of the reduction of the residual magnetism by an alternating current flux, with a frequency of 133 alternations per second; and curve 1, Diagram V, a similar measure when the frequency is at 66 alternations per second. The effect of the magnetically compensated current as given by these curves is about one-fourth of the total effect of the current and circular magnetic effect together.

Other Methods.

The following experiments were made to study the effects of electric oscillations on magnetized plates (fig. 3 A) placed in a magnetizing solenoid of very thin sheet iron (trunk covering) cut into strips 7 inches $\times 3/4$ inch and separated by sheets of mica made to project past the edges of the iron an eighth of an inch. This system was connected to a Holtz machine and

Fig. 3.

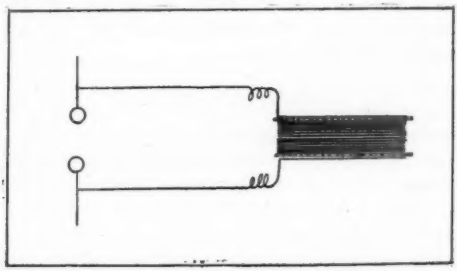


the spark gap adjusted so as to get a rapidly oscillating discharge. The magnet, after being magnetized to a maximum amount of residual magnetism, was placed carefully in the field of a sensitive magnetometer. This magnetometer was made of an astatic magnetic system suspended by a silk fiber in a glass tube. The magnet was so placed that the magnetometer was deflected a few degrees from the meridian. The system was carefully tested to prove the effect produced was not due to conditions external to the iron. Any disturbance in the magnetic field of force thus produced could be

readily detected with a telescope and scale. It was found that an oscillation of the static charge in the "magnetic condenser" produced a demagnetizing effect which could be readily detected with the magnetometer. The effects were lacking when a thin foil condenser was substituted for the iron one.

The residual magnetism of the laminated electro-magnet was also found to be affected by the oscillating electric charges, when connected in series, fig. 3 B, with a condenser to the terminals of the static machine. The amount of this effect was approximately equal to the effect when the magnet was used as a condenser.

Fig. 4.



Another test, fig. 4, was made by placing a pile of these japanned iron sheets between terminals of tinfoil which were insulated from the iron by mica. This proved to be just as effective in producing results as the other method. The frequency of oscillation was an indeterminate factor and did not seem to affect the results, as the demagnetizing effect was apparently produced during the first oscillations. A single spark between the terminals of the machine, in most cases, proved to be as effective as a continuation of the oscillatory discharges.

NOTE.—This work was done at the University of Nebraska under the immediate direction of Dr. D. B. Brace, and much of the success of the investigation was due to suggestions offered by Dr. Brace and by Professor B. E. Moore.

Physical Laboratory, University of Nebraska,
Lincoln, Nebr.

ART. XVIII.—*Nepheline and other Syenites near Port Coldwell, Ontario;* by A. P. COLEMAN.

A FEW years ago some very interesting dikes of a rock containing analcite named "heronite" or analcite tinguaite were described by the writer from the north shore of Lake Superior between Heron Bay and Peninsula on the Canadian Pacific railway;* and the opinion was expressed that nepheline rocks should be found connected with them somewhere in the region. Dr. Adams also has suggested the same idea, basing his belief on some rock specimens from the region of Peninsula in the Geological Survey collection. They are augite syenites of an unusual kind often associated with nepheline syenites.†

In connection with an excursion to the iron range of the Slate Islands an opportunity was taken to examine the railway and shore near Port Coldwell, and it was intended to visit Pic Island a few miles off shore, where Professor Pirsson and others have suggested that nepheline rocks would probably be found, but unfortunately no suitable boat could be got at that little harbor, and this had to be given up.

No syenites of any kind were found between Heron Bay and a point three miles east of Peninsula, where augite syenite had been obtained a few years before; but west of Peninsula, more than half way to Port Coldwell, considerable stretches of nepheline syenite were discovered. So far as the study of the specimens has gone one can say that a great area of syenites and associated rocks rich in alkalies, derivatives of a magma differentiated into a whole series of related species, like those so elaborately described by Brögger in the Christiania region of Norway, occurs in this region.

The first rock of the group, going west, is the dark augite syenite which commences three miles east of Peninsula, and with some interruptions of red syenite and more basic rocks extends to a long trestle at mile 818, a distance of nine or ten miles, with an unknown width. From the trestle west to a cutting beyond Peninsula, the prevalent rock is a gray or purplish gray nepheline syenite, having an extent of about four miles. It is probable that detailed mapping of this little explored region would show large areas of this syenitic group of rocks, including Pic Island, and it is hoped that in the future these interesting eruptives may be studied more at length.

The only previous references to this group of syenites are to

* Bureau Mines, Ontario, 1899, pp. 172–174; and 1900, pp. 186–191.
† Jour. Geol., vol. viii, No. 4, pp. 322–325.

be found in the reports of the Geological Survey of Canada,* where rocks containing red and white feldspar, some grains of orange-red elaeolite, and a few zircons, are said to occur in Pic Island and the mainland to the north; and of the Bureau of Mines,† where the occurrence of augite syenite and other associated rocks is referred to, though the nepheline rocks were overlooked. Acknowledgments must be made to Professor L. V. Pirsson and Dr. H. S. Washington for having been good enough to send chips and larger specimens of various nepheline syenites and related rocks from other localities which have proved most useful for comparison; and to Professor Pirsson for suggestions as to rock relationships.

Nepheline Syenites.

The syenites and associated rocks are very well exposed between miles 818 and 822 in the numerous rock cuts and cliffs where the railway winds along the rugged shore of Lake Superior, so that an almost continuous section is presented. The first nepheline syenite observed is just east of the long trestle at Red Sucker lake, where it forms irregular dikes and larger masses in gabbro, which appears to be the older rock of the two; and similar relations are found at the rock cut west of the trestle, though red syenite interrupts it at the third cutting. Beyond this, toward the west, hills of nepheline syenite rise 200 or 300 feet above the lake and continue with few interruptions to Port Coldwell station and the next cutting beyond it, the last point where it was observed being a little beyond mile 822. The second cutting west of the station is in red syenite. The rock varies from almost compact to very coarse-grained kinds having crystals an inch or more long; and in color from pale to dark gray, sometimes running into purplish tones or having brillant red spots. The black hornblende and augite crystals stand out sharply giving a fresh look to the rock, which unfortunately is not borne out in thin sections. In some specimens the hornblende crystals are long slender prisms, but in others they are short and stout. The different textures are often mixed intimately, fine-grained parts enclosing coarser grained ones or the opposite; and large or small blocks of the gabbro mentioned above are enclosed in the nepheline syenite. Dikes of a fine-grained purplish gray rock, sometimes with the look of an amygdaloid, cut the syenite; and last of all, there are sharply defined dikes of black diabase.

In general appearance the nepheline syenites are very different from those of Eastern Ontario, never showing the

*1846-7; also 1863, p. 80. †1897, p. 147.

gneissoid structure so common there, nor having dikes of pegmatitic rock consisting of large individuals of nepheline and muscovite. Nor are they like specimens from Barkevig, Norway, nor Litchfield, Maine, but some of them have much the appearance of specimens sent by Professor Pirsson from Highwood Mts., Montana, and Red Hill, Moultonborough, New Hampshire, having a tendency to flat plate-like forms of the feldspars, and long prisms of the darker minerals. These would apparently be classed by Professor Brögger as foyaites, though unlike a specimen of foyaite from Lougenthal, Norway, sent me by Dr. Washington.

In the considerable number of specimens collected near Port Coldwell four fairly well marked types may be distinguished, so far as megascopic structure is concerned:

1. Medium to coarse-grained gray rocks having a dioritic appearance with light and dark minerals in about equal amounts and the grains isodiametric.
2. Medium-grained, reddish, purplish or violet-gray rocks, with about twice as much of the lighter colored minerals as of the darker ones, and with a tendency to plate-like or elongated forms in the minerals.
3. Violet-gray, fine-grained rocks with porphyritic feldspars and other minerals.
4. Narrow veins of coarse-grained rocks, often mottled with red, gray and black.

There are, however, many intermediate varieties between the four here mentioned, illustrating the usual variability of the nepheline rocks.

1. The first variety occurs as fresh looking material about two miles east of Port Coldwell, and was supposed to be diorite when collected. The white minerals are nepheline, orthoclase, and a less amount of finely striated plagioclase having a very small extinction angle, probably oligoclase; all badly weathered and turbid, the nepheline sometimes changed into a brownish substance having aggregate polarization, perhaps a zeolite. The dark minerals include hornblende in fairly well formed crystals having a pleochroism of dark green, brownish green and brown, and an extinction angle of 23°; and also augite in about equal amounts, sometimes enclosed in the hornblende. The augite has a slight pleochroism, sea-green, gray-green and brownish green, but its extinction angle is normal and the nearly rectangular cleavages in cross sections show that it is really a pyroxene. The only accessory minerals noticed are magnetite and apatite, both in considerable quantities.

A very similar but duller rock occurs in the first railway cut west of Port Coldwell, with the difference, as seen under the microscope, that the hornblende is dark brown and the augite

grayer and not pleochroic. One or two large masses of magnetite and serpentine probably represent olivines completely decomposed.

2. The gray or purplish gray variety, with relatively small amounts of the dark ingredients, contains all the minerals mentioned as belonging to No. 1, with the exception of the probable olivine; but the ferro-magnesian minerals are, of course, less in amount, and occasionally a little brown biotite occurs, in addition to the hornblende and augite. The red color of spots in the rock is due to infiltration of iron oxide in portions of nepheline completely changed to zeolites, and the usual reddish or purplish tone of the rock is due to the general diffusion of the same oxide. As distinguished from the previous variety this one is leucocratic. In some examples the minerals have plate-like or long prismatic forms with a suggestion of the trachytic structure. In one section the augite is almost entirely replaced by hornblende, often dark brown in the middle and green at the edge with very deep colors but not strongly pleochroic, perhaps barkevitic in character.

3. The porphyritic varieties of the nepheline syenite occur partly a mile or two east of Port Coldwell and partly to the south of the station near the harbor. Specimens from the former locality are dark bluish gray, fine-grained, with porphyritic feldspar, nepheline (rarely) and hornblende crystals.

One thin section from mile 819 shows very small crystals of nepheline having the prism and basal planes, enclosed in orthoclase and possibly oligoclase, as well as in hornblende, the latter mineral forming sieve-like structures, the holes being filled with lighter minerals, a good example of poecilitic intergrowths. The other minerals are augite, magnetite and apatite. A second specimen shows less of the poecilitic intergrowths but contains one or two long porphyritic prisms of nepheline.

Porphyritic examples from south of the station have a purplish gray ground in which bluish crystals of feldspar and black crystals of biotite are embedded. The groundmass does not differ much from the former rock, but the numerous phenocrysts are orthoclase, oligoclose and brown biotite, having strong dichroism.

4. The fourth variety forms narrow pegmatitic veins in the other varieties, and consists of the same minerals but of larger dimensions, sometimes more than an inch in length, though never rivaling the giant nepheline pegmatites of Eastern Ontario, as described by Dr. Adams, with crystals more than a foot long. The nepheline in the Port Coldwell specimens is often changed to a turbid orange-red material, mentioned by Sir William Logan as elaeolite,* the feldspars (orthoclase) are

*Geol. Can., 1863, p. 81.

pale gray, and the hornblende prisms black, making a very showy rock. In spite of the striking differences in appearance of the varieties mentioned above, the range of minerals found in the thin sections examined is not great, much less, for instance, than in the nepheline rocks of Dungannon and York branch in Eastern Ontario,* and none of the rarer minerals have been found by myself, though zircon is mentioned in the 1863 report. The absence of muscovite, scapolite, sodalite, and of the usual microcline and microperthite is peculiar; though in some cases weathering has gone so far as perhaps to obscure the structures of the feldspars.

Augite Syenites.

The other important group of rocks in the region includes the augite syenites, which occur in two well marked varieties, one dark brownish gray to black in color, coarse-grained and with more or less of a plate-like character in the feldspars; the other red or reddish gray, finer grained and usually granitic in texture. The first variety is much the more extensive of the two and will be described first.

In the dark variety, which is no doubt the trap that Logan reports from the region, the feldspars are the prominent ingredient, forming broad plates or narrow shining strips, often carlsbad twins, attracting the eye in the sun; while the relatively small amounts of ferro-magnesian minerals escape notice. While dark brownish gray to black is the prevalent color, there are phases of a dull brown or a dull red; and weathered glaciated surfaces may even be white by the bleaching of the feldspar, when the augite and magnetite show as angular or black filling material between the feldspar crystals, which tend to be idiomorphic.

The syenite is always coarse-grained, the crystals averaging about a quarter of an inch in length, and also in breadth when seen broadside, but often only a tenth of an inch in cross section. There are coarse pegmatitic veins in the finer grained rock having individuals of feldspar an inch or two in diameter, and often fairly well built out in occasional cavities.

As this rock has been quarried by the railway for bridge construction, etc., it is easy to get fresh material.

Thin sections consist of feldspar in more or less idiomorphic forms with augite wedged in between, resembling, so far as one can tell from a description, Brögger's laurvikite.† The feldspars show no twin striations but have partly the appearance of microperthite and partly of microcline. They are

* See Bureau Mines, 1899, Corundum and Other Minerals, p. 205, etc.; and Corundiferous Nepheline Syenite, p. 250, etc.

† Zeitschrift für Kryst. u. Min., Band 16, 1890, pp. 29, 30.

fairly fresh and in some directions have a handsome bluish shimmer. No nepheline nor sodalite nor quartz was observed. The dark minerals are chiefly augite with brown interior and dark green exterior, but some dark green and brown hornblende, and some magnetite occur also, as well as apatite.

An analysis of this rock made by Mr. A. H. A. Robinson of the Chemical Department of the School of Practical Science, Toronto University, gives the following results in column I:

	I.	II.	III.
SiO_2	58·81	58·88	·980
Al_2O_3	13·37	20·30	·131
Fe_2O_3	3·88	3·63	·024
FeO	6·97	2·58	·097
MnO	0·20	----	
MgO	0·51	0·79	·012
CaO	3·89	3·03	·069
Na_2O	4·96	5·73	·080
K_2O	5·42	4·50	·056
H_2O at 100° C.	0·29	1·01	
H_2O above 100° C.	0·75		
TiO_2	0·75		
P_2O_5	0·31	0·54	
Total	100·06	100·99	

Specific gravity at 17°·5 C., 2·75.

For comparison an analysis of Norwegian laurvikite from Byskoven, Laurvik, by A. Merian is given in column II.* The two analyses agree fairly closely except for the relative proportions of alumina and of ferrous iron oxide, which differ greatly. The analysis shows the rock consists largely of microcline and microperthite, the small amount of magnesia and large amount of ferrous oxide that the augite must consist mostly of the hedenbergite molecule. The amount of alumina, though smaller than in the laurvikite, is that which is required by the soda and potash to turn them into feldspars and is therefore correct, as shown in the molecular ratios given in column III.

Associated with the dark augite syenites with plate-like feldspars are numerous other varieties in much smaller amounts, some merely having the red color of the ordinary syenite, due to diffused hematite particles, but with the same ingredients and the same shape of the feldspars; others differing more widely in appearance and composition, but all more weathered and less satisfactory for study with the microscope. It will be sufficient to refer to the kinds having granitic structures,

* Ibid., p. 30.

grains with equal diameters. These are on the average finer grained than the Laurvikitic syenite, and may be divided into leucocratic red syenites with comparatively little of the ferromagnesian minerals; and melanocratic varieties containing more than half dark minerals. It must be admitted that the term leucocratic syenites is not happy for the less basic varieties, since they are strong red and not white or pale colored. Several specimens from east of Port Coldwell are in reality quartz syenite consisting of feldspar pegmatitically intergrown with quartz, and small quantities of hornblende, augite, magnetite and apatite. The feldspars, which tend to be porphyritic, so far as their weathered condition permits one to decide, are orthoclase, microcline and oligoclase. These rocks seem to have the same composition as Brögger's nordmarkites, though no mention is made of pegmatitic intergrowths in the latter rocks.* Aegirite has not been recognised in the rocks from Port Coldwell, another point of distinction.

The melanocratic syenites, consisting to the extent of at least half of dark colored minerals, are dark gray rocks, usually with a red tinge, not very coarse-grained, with about equal diameters to the grains. The light colored minerals are orthoclase, some plagioclase and occasionally nepheline; the dark ones hornblende, pale blue-green augite and brown biotite in not far from equal amounts: while magnetite and apatite are always present, the latter often as numerous large prisms. They appear by analogy to be related to the essexites.

Plagioclase Rocks.

Three kinds of plagioclase rocks accompany the syenites of the Port Coldwell region, coarse-grained gabbro-like rocks older than the syenite and penetrated or carried off as blocks by the nepheline syenite; fine-grained gray-brown rocks occurring as dikes without well defined edges, in the nepheline syenite; and green-black dikes of diabase or diabase porphyrite, which are latest of all,

The gabbro is a speckled gray, coarse-textured rock showing plates of mica and often a few porphyritic plates of plagioclase megascopically. Thin sections are made up of half or less than half of a plagioclase having the extinction angle of andesine or sometimes labradorite; of pale bluish green augite, often idiomorphic, and brown biotite in about equal amounts, while brown hornblende and olivine are in smaller quantities. Magnetite and apatite in thick prisms are the chief accessories; and serpentine, chlorite and iron oxides occur as secondary products. In one section the biotite surrounding

* Ibid., p. 55.

a weathered olivine crystal is modified so that the parts nearest the olivine are more strongly dichroic than the rest, bright green and orange-brown in the two directions.

The fine-grained dikes of brownish plagioclase rock are not very sharply defined as a rule, perhaps because they were erupted before the mass as a whole had completely cooled down. In many cases these rocks are specked with white or pale flesh-colored spots as if amygdaloidal, and they often contain what seem to be fragments of an older, fine-grained reddish rock.

The general mass of these rocks consists of some greatly weathered, lath-shaped plagioclase, partly with a radiating arrangement, enclosing biotite, augite, and magnetite in larger amounts. In this groundmass are often well-formed crystals of augite, sometimes in groups, pale green or brown, somewhat dichroic and with a zonal structure; and of dark brown hornblende. The lighter patches, suggesting amygdaloids, are composed chiefly of plagioclase, often with well-shaped prisms projecting inwards, the center being of some transparent mineral having low double refraction, perhaps a zeolite. There are a few prisms with parallel extinction, probably nepheline, though so badly weathered as to leave their character uncertain. Without an analysis it would be difficult to place this rock with certainty, so for the present it will be left unnamed.

The dikes of dark gray or black diabase and diabase porphyrite have been little studied. The only one of which thin sections have been made is an olivine diabase with comparatively little augite, often in slender fibers or prisms having the usual extinction angle, but sometimes as broader portions between feldspar laths. The magnetite, too, has elongated rod-like forms, and when the numerous needles of apatite are included, there is evident a tendency to elongation in almost all the constituents of the rock. The large well-formed crystals of olivine, still fairly fresh, are, however, an exception to the rule just mentioned. These quite fresh rocks are probably of Keweenawan age like most of the diabase dikes on the north shore of Lake Superior, while the other eruptives described appear to be older, though not so old as the Huronian schists which they penetrate.

It is believed that with the possible exception of the gabbros, which may be older than the syenites, and the diabases which are distinctly younger, all the rocks which have been referred to belong to the same magma and represent phases of differentiation. The dikes of heronite or analcite tinguaite, though found several miles to the east of the nearest syenite, are to be looked on, no doubt, as split off from the large mass described.

The older nepheline or elaeolite rocks and their associates can no longer be considered rare. In the province of Ontario they are known to occur very widely spread in Dungannon and adjoining townships, where they were first noticed by Dr. Adams, and where they have been followed up for many miles by Professor Miller because of their connection with the corundum-bearing band of the Laurentian. The series of eruptives described in this paper form another large mass of nepheline syenites and related rocks, though of a very different type; and the malignites described by Dr. Lawson from Poohbah Lake, west of Lake Superior, make a third, each with ite own peculiarities differing markedly from the others. The nepheline rocks of Montreal make another Canadian locality, though on a small scale, and with their alnöite dikes, as described by Dr. Adams, present still another type; the whole illustrating strikingly the great variability of this group of plutonic and dike rocks as contrasted with most others.

To refer to the areas described in the United States by Pirsson, Washington, Osann and others, would lead too far; and a mere list of the localities in Europe, India, South America, etc., would require considerable space.

In concluding this notice of the Port Coldwell and Peninsula syenitic rocks, it should be mentioned that a number of them are handsome ornamental stones, as proved by polished specimens prepared by the Bureau of Mines for the Buffalo Exposition, where they attracted considerable attention. The dark gray augite syenite with its gleams of blue from the feldspars is a particularly fine stone, resembling the famous Norwegian syenite though on the whole finer in grain. As it can be obtained close to the Canadian Pacific railway and beside an excellent harbor on Lake Superior, in quarries affording blocks of almost any required dimensions, it should prove of importance in the future.

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Art. XIX.—*The Double Ammonium Phosphates in Analysis;* by Martha Austin.

[Contributions from the Kent Chemical Laboratory of Yale University—CIX.]

The function of ammonium salts in the formation of double ammonium phosphates for the purposes of analysis has been the subject of a good deal of study. Manganese, which tends to fall as the tribasic phosphate, $Mn_3P_2O_8$,* appears in the presence of a sufficiency of ammonium salt in the form of the ammonium manganese phosphate $(NH_4)MnPO_4$, which gives the pyrophosphate, $Mn_2P_2O_7$, on ignition. Magnesium,† on the other hand, tends to pass under the influence of ammonium salt toward the condition of the diammonium magnesium phosphate which yields the metaphosphate on ignition. Further, in the cases of zinc and cadmium‡ it has been my experience that the presence of a considerable amount of ammonium salt is essential to the precipitation of the ideal double ammonium phosphates of both these elements, although in the case of cadmium, too large an amount of the ammonium salt prevents complete precipitation and apparently occasions the formation of a phosphate too rich in ammonia. The solvent effect of the reagents in the case of mercury phosphate‡ is very great, yielding a new salt the composition of which has not been investigated in recent years. Beryllium§ is only partly converted to that ammonium beryllium phosphate which yields the pyrophosphate on ignition, even in the presence of large amounts of ammonia salt. Neither an ammonium salt nor ammonia in solution converts the phosphates of barium, strontium, and calcium‡ to the double ammonium phosphates. Of these three elements barium alone falls in the form of the hydrogen barium orthophosphate. In certain recent articles upon the precipitation of the double ammonium phosphates some of the facts mentioned above have been called in question.

In the determination of zinc and manganese Dakin‖ has proposed to substitute ammonium phosphate as the precipitant in place of microcosmic salt (hydrogen ammonium sodium phosphate) in presence of a considerable amount of ammonium chloride, and to wash with a one per cent solution of the precipitant followed by alcohol. Dakin's analytical results, taken without scrutiny, would seem to show that the precipitate pro-

* Gooch and Austin, this Journal, vi, 233.

† Gooch and Austin, this Journal, vii, 187. Neubauer, Zeitschr. anorg. Chem., ii, 45–50; iv, 251–266; x, 60–65; Zeitschr. angew. Chem., 1896, 435–440; Jour. Am. Chem. Soc., xvi, 289.

‡ Austin, this Journal, viii, 206.

§ Roessler, Zeitschr. anal. Chem., xvii, 148.

‖ Chem. News, lxxxii, 101; lxxxiii, 37.

duced by ammonium phosphate (in only moderate excess) and washed with a one per cent solution of the precipitant and alcohol has the ideal constitution of the double phosphate and leaves upon ignition the pyrophosphate.

From the standpoint of theory it is difficult to see why the ammonium phosphate should be more effective in producing the normal ammonium double salt than is hydrogen ammonium sodium phosphate in amount sufficient to supply the ammonium equivalent, or than a mixture of the equivalent amount of any soluble phosphate in association with enough ammonium salt to supply the same amount of the ammonium radical or ion. Whether the conversion of the tribasic phosphate of the type $\overset{II}{R}_3P_2O_8$ to the double ammonium phosphate of the type $(NH_4)\overset{II}{R}PO_4$ be viewed either as dependent upon the interaction according to mass of reagents assembled, or from the point of view of the ion theory,* the action of a solution of ammonium phosphate should not differ much from that of equivalent amounts of other ammonium salt and soluble phosphate. My own experience with the double ammonium zinc phosphate confirms this view.† In the following table are reproduced from my former paper the data of certain experiments bearing upon this point.

$Zn_2P_2O_7$ corresponding to $ZnSO_4$. Taken. grm.	Found. grm.	Error in terms of $Zn_2P_2O_7$. grm.	Error in terms of Zinc. grm.	Zinc left in the filtrate. grm.	$(NH_4)_2PO_4$. grm.	NH_4Cl. grm.	Time of standing. hours.
			A				
(1) 0·6355	0·6206	0·0149—	0·0060—	trace	3·13	----	1½
(2) 0·6355	0·6254	0·0101—	0·0040—	trace	3·13	----	16
(3) 0·6355	0·6300	0·0055—	0·0022—	trace	3·13	----	16
			B				
					$HNaNH_4PO_4.4H_2O$ grm.		
(4) 0·6355	0·6271	0·0084—	0·0034—	trace	4·47	0·5	1
(5) 0·6355	0·6256	0·0099—	0·0040—	none	4·47	0·5	20
			C				
(9) 0·6355	0·6335	0·0020—	0·0008—	none	4·47	10	16
(10) 0·6355	0·6381	0·0026+	0·0010+	none	4·47	20	½
(11) 0·6355	0·6379	0·0024+	0·0009+	none	4·47	20	2
(12) 0·6355	0·6386	0·0031+	0·0012+	none	4·47	20	½
(13) 0·6355	0·6393	0·0038+	0·0014+	none	4·47	20	½
(14) 0·6367	0·6355	0·0012+	0·0005+	none	4·47	30	16

* Gooch and Austin, this Journal, vi, 233; Boettger, Ber. Chem. Gesell., xxxiii, 1019.

† This Journal, viii, 210.

The results of the experiments of Section B, in which the precipitation was made by microcosmic salt in presence of a small amount of ammonium chloride, show an average constitution of the precipitate similar to that of the precipitate obtained in A by an equivalent amount of ammonium phosphate, but the results of both series, A and B, vary considerably from the ideal much more closely approximated in the experiments of C, in which precipitation was made in the presence of a large excess of ammonium chloride. With these results those of Dakin are not in accord. Upon examination, however, Dakin's procedure appears to be open to criticism.

In the first place, it appears that the asbestos employed by Dakin was of the hydrous (serpentine) variety, which disintegrates when heated and is readily acted on by many reagents. Though previously treated with hydrochloric acid, it was, by Dakin's account, perceptibly soluble in a solution of ammonium phosphate. After drying at 100°–105° the crucible and felt lost some decimilligrams on ignition. It was on this account that Dakin weighed precipitate and filter, after drying at 100°–105°, when the double phosphate was to be estimated as such, or after ignition when the zinc pyrophosphate was weighed, and then, dissolving the precipitate in nitric acid, reweighed the crucible and asbestos, and by difference from the former weight obtained the apparent weight of the precipitate. The inevitable loss through disintegration or solubility of the filter in the nitric acid used to dissolve the precipitate in Dakin's procedure, must raise the corresponding apparent weight of the precipitate itself. Any series of results based upon the use of such material must of necessity be imperfect to the extent to which the ignited filter disintegrates or dissolves under the action of the nitric acid used to dissolve the precipitate.

Anhydrous (amphibole) asbestos, the material of which I made use, is insoluble, under the conditions of analytical work, in ordinary reagents including even the strong acids, as has been abundantly shown.* It is likewise completely insoluble in ammonium phosphate under the conditions of the work described, as I have found by experiment. Herein lies one cause of difference between Dakin's results and mine.

A second source of error in Dakin's procedure is found in the fact that precipitates of the double ammonium phosphates are washed in a one per cent solution of the reagent, ammonium phosphate followed by "redistilled alcohol." Dakin calls attention to the fact that absolute alcohol must not be

* Gooch, Am. Chem. Jour. i, 317. Mar, this Journal, xii, 288; xliii, 521. Browning, this Journal, xliv, 399. Phinney, this Journal, xlv, 468.

used, but makes no mention of the exact strength of the alcohol employed in his work.

In order to test the insolubility of ammonium phosphate in alcoholic washing I have made various experiments, the details of some of which are given in the following account. Portions of a solution of manganous chloride, standardized as the sulphate according to the method* described in a former paper, were carefully measured from a burette, ammonium chloride and microcosmic salt were added in the proportions formerly recommended, and precipitation of the ammonium manganese phosphate was completed exactly as directed. After cooling, the precipitates were collected on asbestos under pressure in a perforated platinum crucible. In the experiments the results of which are given under A of the table, the precipitate was in each case washed with distilled water made faintly ammoniacal, while in those recorded under B, C, and D of the table the precipitate was washed with two hundred cubic centimeters of a one per cent ammonium phosphate solution, and rinsed with forty cubic centimeters of alcohol of different strengths,—sixty, eighty and eighty-eight per cent,—applied in successive portions.

$Mn_2P_2O_7$ corresponding to $MnCl_2$ taken.	Washed with ammoniacal water. A	Washed with 1% $H(NH_4)_2PO_4$ rinsed with 60% alcohol. B	Washed with 1% $H(NH_4)_2PO_4$ rinsed with 80% alcohol. C	Washed with 1% $H(NH_4)_4PO_4$ rinsed with 88% alcohol. D
grm.	grm.	grm.	grm.	grm.
0·3020	0·3042	0·3050	0·3058	0·3066
	0·3020	0·3041	0·3074	0·3086

From these experiments it appears that the procedure involving the washing of a precipitate of ammonium manganese phosphate by a one per cent solution of ammonium phosphate, draining with the pump, and then completing the washing with alcohol, results in a contamination of the precipitate proportionate to the strength of the alcohol used. Even the thin felt of asbestos alone when washed with ammonium phosphate followed by alcohol retains amounts of

Weight of asbestos felt.	Weight of asbestos felt after washing ten times with a 1% solution of ammonium phosphate and rinsing with distilled water.	Weight of asbestos felt after washing with a 1% solution of ammonium phosphate and rinsing with alcohol of the strength given.		
		60%	80%	88%
grm.	grm.	grm.	grm.	grm.
0·0681	0·0681	0·0682	0·0684	0·0686

* This Journal, v, 209.

that salt proportionate to the strength of the alcohol employed. This is shown in the accompanying statement.

So it appears that in washing with ammonium phosphate and alcohol, according to Dakin's procedure, the precipitate of the double ammonium phosphate must be loaded with foreign material to a degree dependent upon the conditions. This error is in the same direction as that introduced by the solubility of the serpentine in nitric acid. With these two sources of error active, the most remarkable thing about Dakin's results is that they happen to agree so closely with mine, the solubility of the serpentine asbestos and the insolubility of the ammonium phosphate in alcohol together counterbalancing the deficiency due to imperfect constitution of the double ammonium phosphate.

As to the experience of Miller and Page* upon the ammonium cadmium phosphate, in consequence of which they concluded not only that my method for the estimation of cadmium is unsatisfactory, but that "asbestos filters should be avoided on account of the solvent action of either ammonium phosphate or nitric acid," it is sufficient to direct attention to the fact that their analytical examination of this process is wholly worthless by reason of their use of serpentine asbestos.

With suitable anhydrous asbestos at disposal, the estimation of magnesium, manganese, cadmium and zinc precipitated as the double ammonium phosphates, according to the directions and with the precautions laid down in the former papers from this laboratory to which reference has been made, is perfectly practicable. Concerning the manganese and zinc phosphates, in particular, it may be reiterated that with a sufficiency of ammonium salt, preferably the chloride, and with an excess of the precipitant present, the precipitation is complete and the phosphate formed of nearly ideal constitution. In the precipitation of the ammonium cadmium phosphate the proportions of the reagents must be regulated with care. The use of ammonium phosphate followed by rinsing in alcohol is not only wholly unnecessary but always altogether undesirable.

* School of Mines Quarterly, xxii, 391.

ART. XX.—*On the Electrical Resistance of Glass, Quartz, Mica, Ebonite and Gutta-percha;* by OGDEN N. ROOD, Professor of Physics in Columbia University.

IN the August number of this Journal for 1901,* I published an account of an electrometer intended for measuring very high electrical resistances, and at the same time described a set of units of resistance that had been made with its help, the highest of which reached to 14,000,000 of megohms. Since then, with a similar set of high resistances, measurements of the external and internal resistances of certain insulating substances have been undertaken, which may not be without interest, in spite of the fact that they are to be regarded as first approximations. The reason of this limitation is to be found, not in any especial uncertainty in the resistance of the units employed, but in another direction, viz: metallic connection with substance under experiment is necessary, but mere mechanical contact is not sufficient to abolish contact-resistance, which is apt to be quite large, and various expedients were adopted to remove this troublesome difficulty. The best of these appeared to be the application of an amalgam of tin and mercury, of the consistence of soft butter, to the parts in question, but others were also employed; as, for example, in the case of gutta-percha, it seemed fair to cement the tinfoil to it with a liquid solution consisting mainly of gutta-percha, while in the case of ebonite, a metallic powder was attached to its surface by a very weak solution of shellac, and this again overlaid by tinfoil. Another source of error lies in the *time* of exposure to the electrical current, as the resistance of the substance through which it flows is apt to increase with the time. The initial resistance, or more properly the average resistance during the first stroke of the electrometer, was in each case noted, and an effort was made to adjust matters so that this should be about one minute, but very often it differed considerably from this amount of time, a drawback which could only be remedied by a large amount of extra labor and expenditure of time. It is owing then to these two factors that the measurements given below are to be regarded as first approximations. On the other hand, no difficulty was encountered in causing the current to pass through glass, quartz, mica, gutta-percha and ebonite, or to flow over their surfaces.

Mode of experimenting.—Mr. H. C. Parker determined for me the resistance of five small units in the ordinary way, and

* This Journal, vol. xii, p. 91.

these were used to build up a large set of high resistances similar to those described in my article already alluded to. All this was done twice, and during these operations, the resistances of the insulating substances under experiment were determined, as far as possible, immediately. In the case of surface conduction, tinfoil was cemented on the ends of the strip and fringed with a line of metallic powder. For internal conduction, metallic surfaces were fastened to opposite sides of the plate, which was provided with a guard-rim of tinfoil, cemented with a solution of gum arabic and glycerine all around its edges, and grounded to prevent surface electricity from reaching its opposite side; a precaution which in the case of quartz and ebonite is not necessary, quartz giving the same result with and without the guard-rim, and the surface conduction of ebonite in dry weather is again still smaller than that of quartz.

In order to compare together the results obtained, those for surface conduction are reduced to the *calculated* resistance that would be offered by *one* surface of one square centimeter between the terminals. For internal resistance, the *calculated* resistance of coatings one square centimeter in area, with a thickness of one millimeter of substance between them, is given. A set of one hundred dry cells was employed in each case; its electromotive force was 150 volts. The striking distance of the electrometer was one millimeter, except in the case of very high resistances, where it was reduced to one-half or one-quarter of a millimeter.

Internal resistance of quartz.—The thickness of the plate was $1{\cdot}71^{mm}$, the metallic coatings, each, one square centimeter in area. Calculating the resistance for a thickness of 1^{mm}, I obtained, on

Feb. 19th	860,000 Ω	Hyg.	18°
" 22d	910,000 "	"	27°

The coatings were composed of an amalgam of tin and mercury.

Internal resistance of glass.—Very numerous measurements were made on plates of ordinary glass, and on others colored by oxide of cobalt, and even one plate of glass $6{\cdot}2^{mm}$ in thickness was employed. The current traversed all of these with a certain facility, but the resistance of the cement used to attach the coatings increased from week to week, and consequently it is not worth while to give any figures at present. The internal and external resistances of two excellent Leyden jars of recent German make were also measured; in both cases the external resistance was very considerably greater than the internal; hence, in use, the main leakage would be through the sub-

stance of the glass. It would, therefore, seem undesirable to obtain capacity by thinness of wall.

Internal resistance of gutta-percha.—Two sheets of gutta-percha were employed, their thickness being 2·79^{mm}. Tinfoil was cemented on them with a solution of gutta-percha, and the results were fairly constant as seen below, where the actual figures obtained are given :

No.	1	6,030,000	Ω	Feb.	19th	Hyg.	18°
"	2	6,270,000	"	"	"	"	"
"	1	5,240,000	"	"	24th	"	27°
"	2	6,640,000	"	"	"	"	"
		6,050,000	"				

Calculating this for a surface of one square centimeter and a thickness of one millimeter, we obtain, 18,500,000 Ω.

Internal resistance of ebonite.—Three plates of this material were used, one having a thickness of 2·29^{mm} ; the other two were only ·5^{mm} thick. The coatings were made of a metallic powder backed by tinfoil, all of which probably did not insure the best possible contact.

Reducing the results to the standard of one square centimeter of surface and a thickness of one millimeter, we have

No.	1	76,400,000	Ω	Hyg.	32°
"	2	45,200,000	"	"	"
"	3	45,000,000	"	"	"
		55,000,000	"		

Internal resistance of mica (muscovite, beautiful large sheets). —The thickness of No. 1 was ·122^{mm} ; Nos. 2 and 3 had a thickness of ·32^{mm}. The coatings were made in the same way as with ebonite. Reducing to an area of one square centimeter and a thickness of 1^{mm}, I obtained for

No.	1	100,000,000	Ω	Hyg.	32°
"	2	190,000,000	"	"	"
"	3	110,000,000	"	"	"
		133,000,000	"		

From this it would seem that the internal resistance of mica is somewhat greater than that of ebonite, though, as will be shown later on, its surface resistance is much smaller.

Surface resistance of plate glass (window glass, commercial). —This proved to be unexpectedly regular, in spite of some variations in the hygrometric condition of the air. Two plates were employed, each having a length of 23·7^{cm} between the terminals. The actual figures obtained on three different occasions are as follows :

No. 1	3,400,000	Ω	Feb. 19th	Hyg.	18°
" 2	3,600,000	"	" 22d	"	27°
" 1	3,700,000	"	March 3d	"	32°
" 2	3,600,000	"	"	"	32°
	3,570,000	"			

Calculating this for *one* surface of one square centimeter between terminals gives 1,590,000 Ω.

Surface resistance of cobalt glass.—From previous experiments it was known that the surface resistance of cobalt glass is considerably greater than that of the ordinary varieties of window glass, and the results given below confirm this idea. Four strips were used, with an average length between terminals of 4^{cm}. The experiments were all made on the same day, the hygrometer indicating 34 per cent of moisture. The actual figures obtained are:

No. 1	24,400,000	Ω	Hyg.	34°
" 2	21,700,000	"	"	"
" 3	24,400,000	"	"	"
" 4	21,700,000	"	"	"
	23,000,000	"		

Calculating this for *one* surface of one square centimeter between terminals gives 22,000,000 Ω.

Surface resistance of mica.—Four slips of mica were used; the distance between terminals was 2·5^{cm}; the actual figures were:

No. 1	29,900,000	Ω	Hyg.	35°
" 2	25,600,000	"	"	"
" 3	39,400,000	"	"	"
" 4	31,600,000	"	"	"
	31,600,000	"		

Calculating for *one* surface of one square centimeter, we obtain 50,760,000 Ω.

Surface resistance of gutta-percha.—Two slips of the material were used, the distance between terminals being 1^{cm}. The actual figures were:

No. 1	17,500,000	Ω	Feb.	20th	Hyg.	17°
" 2	18,900,000	"	"	"	"	"
" 1	13,000,000	"	"	28th	"	35°
" 2	7,700,000	"	"	"	"	"
" 1	18,800,000	"	March	3d	"	32°
" 2	19,500,000	"	"	"	"	"
	16,000,000	"				

Calculating the mean for *one* surface of one centimeter between terminals, we have 432,000,000 Ω.

Surface resistance of quartz (crystal).—The distance from terminal to terminal was $1{\cdot}5^{cm}$; the actual figures were:

76,000,000	Ω	Feb. 20th	Hyg.	17°
75,000,000	"	" 27th	"	34°

Calculating the mean for one surface of one square centimeter, we have 521,000,000 Ω.

Surface resistance of ebonite.—Two strips were used; the breadth of gaps was in one case $5{\cdot}5^{mm}$, in the other $6{\cdot}2^{mm}$.

Calculating the resistances actually obtained, for one surface of one square centimeter we have

No. 1	1,107,000,000	Ω	Hyg.	34°
" 2	2,940,000,000	"	"	"
	2,000,000,000	"		

These results are sufficiently discordant; those with quartz are scant, but damp weather prevented additional observations.

In closing this article, I give two determinations of the resistances employed in the investigation, for the purpose of showing the degree of accuracy readily obtainable in the process of building up high units by my method. The two operations were separated by an interval of about a week; the units were one year old.

53,760	53,830 Ω
71,860	72,370 "
81,400	80,500 "
244,000	241,000 "
220,000	205,000 "
297,000	292,000 "
389,000	384,000 "
1,161,000	1,163,000 "
585,000	554,000 "
1,565,000	1,504,000 "
1,401,000	1,380,000 "
2,246,000	2,193,000 "
2,891,000	3,140,000 "
2,203,000	2,193,000 "
3,707,000	3,432,000 "
2,990,000	3,130,000 "
3,070,000	3,130,000 "
1,958,000	1,803,000 "
7,808,000	8,194,000 "
7,902,000	8,460,000 "
8,720,000	8,540,000 "
5,584,000	5,560,000 "
8,120,000	8,194,000 "
6,780,000	6,906,000 "

New York, June 1st, 1902.

SCIENTIFIC INTELLIGENCE.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *American Association.*—The fifty-first annual meeting of the American Association for the Advancement of Science was held at Pittsburg from June 28 to July 3. The President of the meeting was Professor Asaph Hall, U. S. N. The attendance was rather large, 431 members registering; the number of papers read was also very considerable, amounting to some 320, including the addresses delivered and also papers before the affiliated societies. The local committee provided some fifty excursions for the entertainment and instruction of the members and the many manufacturing establishments of the region offered a rich field for study and observation. The address by the retiring President, Professor Charles S. Minot, was upon the subject "The Problem of Consciousness in its Biological Aspects;" this is printed in the number of Science for July 4 and the following issues of the same journal give the other addresses and general proceedings in great fullness.

The officers elected for the following year are as follows:

President: Ira Remsen, Johns Hopkins University.

Vice Presidents: Section A, G. B. Halsted, Austin, Texas; B, E. F. Nichols, Dartmouth College; C, C. Baskerville, Chapel Hill, N. C.; D, C. A. Waldo, Purdue University; E, W. M. Davis, Harvard University; F, C. W. Hargitt, Syracuse, N. Y.; G, F. V. Colville, Washington; H, G. M. Dorsey, Chicago; I, H. T. Newcomb, Philadelphia.

Permanent Secretary, L. O. Howard, Washington; *General Secretary*, H. B. Ward, University of Nebraska; *Treasurer*, R. S. Woodward, New York.

The next meeting of the Association will be held in Washington, D. C., Dec. 29, 1902 to Jan. 3, 1903, during the recently established convocation week.

OBITUARY.

DR. CARLO RIVA, Docent in petrography and Assistant in the mineralogical laboratory of the University of Pavia, was killed by an avalanche June 3d, during the ascent of the Monte Grigna, southeast of Lake Como. Dr. Riva was one of the most promising of the younger petrographers and mineralogists of Italy and had already published several papers describing rocks from the Monte Adamello and other regions in the Alps, from Italy and Sardinia; he was also correspondent for the Zeitschrift für Krystallographie, and gave promise of a long and productive career. His American friends, who were familiar with his charming personality, will learn with deep regret of his untimely end.

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" III.	165 specimens of rocks, ...	170	"
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Dynamical and Structural Geology

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Kortfors, Sweden. Of this interesting rock we have but three specimens on hand. The concretions are mainly hornblende imbedded in a coarse-grained light colored granite, making a strong contrast between the matrix and the concretions, the latter being from 2½ to 3 inches in diameter; polished slab 8 x 19 in. in diameter, $20.00; larger, $22.00 and $30.00.

Kangasniemi, Finland. In this rock the concretions are light colored surrounded by bands of hornblende, the compactness of the concretion forming a strong contrast to the coarse crystalline structure of the matrix. The concretions range from 4 to 6 inches in diameter. Specimens from $6.00 to $30.00.

Quonochontaug, Rhode Island. This is the only Orbicular Granite we have ever seen from America. The concretions are mainly hornblende with granite centers intermediate in color between the above two, and average from 1 to 2¾ inches in diameter; polished slices from $6.00 to $13.00.

Orbicular Diorite (Napoleonite, Corsite). This well-known rock is now quite rare. The concretions, consisting of Anorthite, Hornblende and some Quartz, are comparatively uniform in size, averaging about 1¼ inches in diameter; magnificently polished slabs of this rare rock from $4.00 to $15.00.

The above four rocks present a fine suite of concretionary structure as displayed in eruptive rocks; tracings of slices with size and position of concretions sent on application.

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Hot Springs, S. D. We have a few specimens of this beautiful sandstone consisting of narrow layers ranging in color from light yellow to dark purple, showing in some instances from 3 to 10 distinct faults on same slab.

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Three polished slices showing crossed dikes, with a fault at contact of the two dikes, $6.00 to $8.00.

METAMORPHISM.

Blue Pyroxene partially changed to Serpentine, from Gila River, N. M., the centers of these polished slabs being a light azure blue pyroxene with its edges changed to a tranlucent rich colored Serpentine, a beautiful combination of color. We have but a half dozen slices of this rare rock on hand. $3.50 to $6.00.

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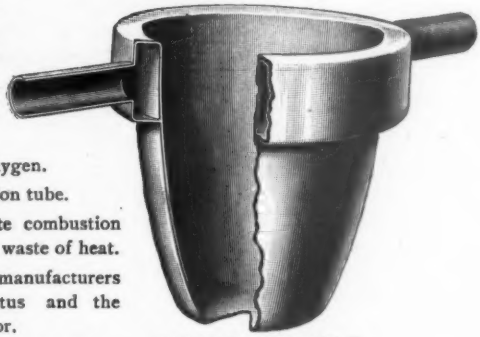

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DANA'S WORKS.

AMERICAN BOOK CO., New York.—**Manual of Geology,** by J. D. DANA. **Fourth Edition,** 1895. 1088 pp. 8vo. $5.00.—**Text-book of Geology** by the same. **5th ed.** revised by Wm. North Rice, 1898. 482 pp. 8vo. $2.00.—**The Geological Story Briefly Told,** by the same. 264 pp. 12mo.

J. WILEY & SONS, New York.—**System of Mineralogy** of J. D. DANA. 6th edit. by EDWARD S. DANA. lxiii, 1134 pp. large 8vo., 1892. $12.50. Appendix I, 75 pp., June 1899. $1.00. 5th edit., 1868, with three appendices, 1872, 1875, 1882. $5.00.—**Manual of Mineralogy & Lithology,** by J. D. DANA. 4th edition. 517 pp. 12mo., 1887, $2.00.—**Text-book of Mineralogy,** by E. S. DANA. Revised edition. 593 pp. 8vo., 1898, $4.00.—**Minerals and How to study them;** a book for beginners in Mineralogy, by E. S. DANA. 380 pp. 12mo., 1895, $1.50.—**Text-book of Elementary Mechanics,** by E. S. DANA. 300 pp. with numerous cuts, 12mo., 1881.

DODD & MEAD, New York.—**Corals and Coral Islands,** by J. D. DANA. 440 pp. 8vo. 3d ed., 1890.—**Characteristics of Volcanoes,** with contributions of facts and principles from the Hawaiian Islands, by J. D. DANA. 399 pp. 8vo. With illustrations, maps, etc. 1890.

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